PB82-256884

Retention and Transformation of Selected Pesticides and Phosphorus in Soil-Water Systems: A Critical Review

Florida Univ., Gainesville

Prepared for

Environmental Research Lab.
Athens, GA

May 82

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA 600/3-82-060
May 1982

PB82-256884

RETENTION AND TRANSFORMATION OF SELECTED PESTICIDES AND PHOSPHORUS IN SOIL-WATER SYSTEMS: A CRITICAL REVIEW

Grant No. R-805529-01

Editors

P.S.C. Rao and J.M. Davidson
Soil Science Department
University of Florida
Gainesville, Florida 32611

Project Officer

Charles N. Smith
Technology Development and Applications Branch
Environmental Research Laboratory
Athens, Georgia 30613

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA 30613

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TYPING GUIDE SHEET

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/3-82-060
2. ORD Report
3. RECIPIENT'S ACCESSION NO. PB82 25688 4

4. TITLE AND SUBTITLE
Retention and Transformation of Selected Pesticides and Phosphorus in Soil-Water Systems: A Critical Review

5. REPORT DATE
May 1982

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Soil Science Department
University of Florida
Gainesville, Florida 32611

10. PROGRAM ELEMENT NO.
AARB1A

11. CONTRACT/GRANT NO.
R-805529-01

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Research Laboratory--Athens GA
Office of Research and Development
U.S. Environmental Protection Agency
Athens, Georgia 30613

13. TYPE OF REPORT AND PERIOD COVERED
Final, 11/77-10/79

14. SPONSORING AGENCY CODE
EPA/600/01

15. SUPPLEMENTARY NOTES
Editors: P.S.C. Rao and J.M. Davidson

16. ABSTRACT

The current state-of-the-art for measuring or estimating pesticide retention and transformation parameters required in nonpoint source pollution models was reviewed. A data base of sorption partition coefficients, degradatiin rate coefficients, and half-lives for a broad spectrum of pesticides was compiled from a literature survey. Adsorption partition coefficients normalized with respect to soil organic carbon content were approximately constant across soils for a given pesticide. Octanol-water partition coefficients were good predictors of pesticide adsorption parameters. Chemical persistence in soils for a large number of pesticides has been measured under a variety of soil environmental conditions. These data were used to calculate first-order decay coefficients and half-lives. The variability of these degradation parameters for a given pesticide across several soils was within a factor of two. Multiple regression equations that correlated degradation (or disappearance) rates with soil properties could not be developed from the literature data because of inadequate information regarding soil physical, chemical, and environmental conditions during the pesticide degradation studies. Seasonal losses by runoff from agricultural fields were generally less than 0.5 - 1.0 % of the total amount applied. Although pesticide concentrations on the sediment phase of the runoff are larger than those in the water phase, pesticide carried in the water phase accounted for more than 90% of the total mass emission during a given runoff event.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
341

22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

Mention of trade names or commercial products does not consititute endorsement or recommendation for use.

FOREWORD

Environmental protection efforts are increasingly directed towards preventing adverse health and ecological effects associated with specific compounds of natural or human origin. As part of this Laboratory's research on the occurrence, movement, transformation, impact and control of environmental contaminants, the Technology Development and Applications Branch develops management and engineering tools for asssessing and controlling adverse environmental effects of nonirrigated agriculture and of silviculture.

Surface and groundwaters may, under certain conditions, be adversely affected by the presence and/or accumulation of phosphates and pesticides resulting from the application of these chemicals to agricultural lands to maintain current production levels. Because of their water pollution potential, it is important that we understand their fate in the field and distribution in the solid and liquid phases leaving agricultural fields during runoff events. This report presents, based on an extensive literature review, first-order degradation rate coefficients and sorption partition coefficients for a large number of pesticides. The coefficients were evaluated across soils and for different environmental conditions. Transformation rate coefficients and sorption properties of inorganic phosphate were also considered and are presented. The coefficients and soil parameters measured and reported in this manuscript were selected based on their previous and present use in nonpoint source pollution simulations models developed for describing retention and transformation of phosphorus and pesticides within the soil surface and runoff.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA

DROPPED
HEAD
BEGIN
SECTIONS
HERE

ABSTRACT

The current state-of-the-art for measuring or estimating pesticide retention and transformation parameters required in non-point source pollution (NPS) models was reviewed. A data base of sorption partition coefficients, degradation rate coefficients, and half-lives for a broad spectrum of pesticides was compiled from a literature survey. Adsorption partition coefficients normalized with respect to soil organic carbon content were approximately constant across soils for a given pesticide. Octanol-water partition coefficients were good predictors of pesticide adsorption parameters. Chemical persistence in soils for a large number of pesticides has been measured under a variety of soil environmental conditions. These data were used to calculate first-order decay coefficients and half-lives. The variability of these degradation parameters for a given pesticide across several soils was within a factor of two. Multiple regression equations which correlated degradation (or disappearance) rates with soil properties could not be developed from the literature data because of inadequate information regarding soil physical, chemical and environmental conditions during the pesticide degradation studies. Seasonal losses by runoff from agricultural fields were generally less than 0.5 - 1.0% of the total amount applied. Although pesticide concentrations on the sediment-phase of the runoff are larger than those in the water-phase, pesticide carried in the water-phase accounted for greater than 90% of the total mass emission during a given runoff event.

Phosphate sorption parameters (primarily Langmuir constants) were collected from the literature or computed from published adsorption isotherms. Statistical analysis showed that Langmuir sorption parameters, S_{max} and k, each normalized with respect to extractable Fe and Al, were significantly correlated to the extractable metals. The correlations gave higher R^2 values and lower probability levels of significance for oxalate extractable Fe and Al than for citrate-dithionite-bicarbonate extractions. Correlations for other parameters with extractable Fe and Al were less significant. The composition and degree of crystallinity of Fe, Al oxhydroxides appear to be the dominant factors in controlling phosphate sorption. Lack of uniformity in experimental methods used for determining Langmuir sorption parameters was noted during the literature survey. Development of standardized methodology (protocols) for this purpose appears essential for quantification of appropriate sorption parameters.

This report was submitted in partial fulfillment of Grant No. R-805529-01 by the University of Florida under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers the period 1 November 1977 to 31 October 1979, and work was completed as of 31 October 1980.

BEGIN
LAST L
OF TEX

OTTOM OF
MAGE AREA
UTSIDE
IMENSION
OR TABLES
AND ILLUS
RATIONS

PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables ix
Acknowledgments xvii

1. Introduction 1
2. Conclusions 3
3. Recommendations 5

4. Retention of Pesticides in Soils

    Methods for Measuring Pesticide Retention 7
    Time-Dependence of Adsorption-Desorption 11
    Non-Singularity of Adsorption-Desorption 13
    Estimation of Adsorption Partition Coefficients 16
        Influence of Soil Organic Carbon 16
        Octanol-Water Partitioning 19
        Effects of Soil-Particle Size 27
    Pesticide Losses in Runoff 28
    Summary 30

5. Pesticide Transformations in Soils

    Aerobic and Anaerobic Degradation 40
    Quantitative Aspects of Pesticide Transformations 41
    Estimating Pesticide Degradation and Mineralization Rates.44
        Herbicides 45
        Insecticides 52
        Fungicides 56
    Summary 57

6. Partitioning of Inorganic Phosphate in Soil-Water Systems

    Introduction 74
    Models for Equilibrium Sorption-Desorption of Phosphate .79
    Correlation of Phosphate Sorption Parameters and Selected Soil Properties 85
    Estimated Partition Coefficients for Phosphate 104
    Laboratory Measurement of Phosphate Sorption Parameters .113
    Models for Time-Dependence of Phosphate Sorption-Desorption 116
    Mechanisms of Phosphate Sorption 127
    Thermodynamics of Phosphate Sorption Processes 131
    Summary 133

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/4"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

Literature Cited 134

Appendices

- A. Tables of Pesticide Adsorption Isotherm Parameters 158
- B. Tables of Pesticide Transformation Rate Coefficients 200
- C. Tables of Phosphate Sorption Parameters 268

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

FIGURES

Number Page

4-1 Graphical representation of the error introduced by the assumption of linearity when the adsorption isotherms are nonlinear. The numbers on the lines are the values of Freundich constant N (see Eqs. 4-4 and 4-8) 10

4-2 Errors introduced by the assumption that adsorption-desorption isotherms are singular when they are nonsingular (see Eqs. 4-20, 4-21) 17

4-3 Relationship between K_{oc} and K_{ow} values for pesticides reported in the literature 26

6-1 Inorganic orthophosphate speciation in aqueous solutions as a function of pH 77

6-2 Solubility diagram for selected solid phosphate phases (Stumm and Leckie, 1971) 92

6-3 Relationship between Langmuir k normalized with respect to CDB extractable Fe + Al and CDB extractable Fe + Al for selected soils 93

6-4 Relationship between normalized S_{max} and CDB extractable Fe + Al for selected soils 94

6-5 Relationship between lnk and $\ln S_{max}$ for selected soils. Numbers refer to REF in Table 6-2 96

6-6 Relationship between $\ln S_{max}$ and ln CDB (Fe + Al) for selected soils. Numbers refer to REF in Table 6-2 97

6-7 Relationship between $\ln[S_{max}/(\text{CDB Fe + Al})]$ and ln(CDB Fe + Al) for selected soils. Numbers refer to REF in Table 6-2 98

6-8 Relationship between $\ln[S_{max}/(\text{oxFe + Al})]$ and ln(oxFe + Al) for selected soils. Numbers refer to REF in Table 6-2 99

6-9 Relationship between lnk and ln(oxFe) for selected soils. Numbers refer to REF in Table 6-2 100

6-10 Relationship between lnk and ln(oxFe + Al) for selected soils. Numbers refer to REF in Table 6-2 101

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

6-11 Relationship between ln(k/oxFe) and ln(oxFe) for selected soils. Numbers refer to REF in Table 6-2 102

6-12 Relationship between ln[k/(oxFe + Al)] and ln(oxFe + Al) for selected soils. Numbers refer to REF in Table 6-2 103

6-13 Phosphate sorption isotherms for isotherms 5 and 49 (Table A6-4). Solid lines were computed from $S = kS_{max}C$ using the parameters indicated in the figure 105

6-14 Degree of error in using $S' = kS_{max}C$ compared to the Langmuir form, $S = kS_{max}C/(1 + kC)$, as a function of equilibrium phosphate concentration for various values of k 107

6-15 Relationship of the approximate expression for $K_D(=kS_{max})$ and CDB Fe + Al for selected soils. Numbers refer to REF in Table 6-2 108

6-16 Relationship of the approximate expression $(K_D = kS_{max})$ normalized with respect to CDB Fe + Al and CDB Fe + Al for selected soils. Numbers refer to REF in Table 6-2 109

6-17 Phosphate sorption-desorption isotherms for a soil incubated in the presence of phosphate (Barrow and Shaw, 1975) 110

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLES

No. Page

4-1 Summary of Adsorption Partition Coefficient Values Compiled from Published Literature for Several Pesticides and Related Organic Compounds 20

4-2 Summary of Octanol-Water Partition Coefficients (K_{ow}) for Pesticides Compiled from Literature 23

4-3 Adsorption Partition Coefficients (K_D^i and K_{OC}^i) for Various Particle-Size Fractions of Hickory Hill Sediment. (Adapted from Karickhoff and Brown, 1978) 29

4-4 Influence of K_D and ρ_s on the Pesticide Lost in the Water-Phase of the Runoff. Values Shown are % of the Total Loss 29

5-1 Common and Chemical Names of Selected Pesticides 46

5-2 Degradation Rate Coefficients and Half-Lives for Several Pesticides under Laboratory and Field Conditions 58

5-3 Grouping of Pesticides Based on their Persistence* in Soils under Laboratory Incubation Conditions 61

6-1 Assumptions Underlying the Derivations of Adsorption Equations . . 80

6-2 Summary of phosphate sorption parameters and soil chemical properties used in linear regression analysis 87

6-3 Summary of means, standard deviations, and coefficients of variation of sorption parameters and extractable Fe and Al 89

6-4 Summary of estimates obtained from linear regression correlations of phosphate sorption parameters and extractable Fe and Al 95

6-5 Effects of time of desorption and solution/soil ratio during desorption on K_D values obtained on a soil previously incubated with phosphate 111

6-6 Rate constants and activation energies for indigenous phosphate release from Thiokol silt loam.* 119

6-7 Rate constants of phosphate adsorption by $CaCO_3$ and Ca-kaolinite . 121

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

No. Page

6-8 Observed rate constants for the disappearance of phosphate from solutions in the presence of kaolinite and α Al_2O_3 at 25°C 124

6-9 Values obtained when Eq. (3-50)* was fitted to the changes in concentration of phosphate when soils were incubated at a range of temperatures 128

A1 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Ametryne and selected soil properties compiled from the literature. 159

A2 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Amiben and selected soil properties compiled from the literature. 160

A3 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Atrazine and selected soil properties compiled from the literature. 161

A4 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Carbofuran and selected soil properties compiled from the literature. 163

A5 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Chlorobromuron and selected soil properties compiled from the literature. . 163

A6 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Chloroxuron and selected soil properties compiled from the literature. 164

A7 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Chlorthiamid and selected soil properties compiled from the literature. 164

A8 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Cis-Telone and selected soil properties compiled from the literature. 165

A9 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Dicamba and selected soil properties compiled from the literature. 165

A10 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Dimethylamine and selected soil properties compiled from the literature . . 166

A11 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Dipropetryn and selected soil properties compiled from the literature. 166

A12 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Disulfoton and selected soil properties compiled from the literature. 167

A13 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Diuron and selected soil properties compiled from the literature. 168

A14 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Fenuron and selected soil properties compiled from the literature. 172

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin)
(4-76)

No. Page

A15 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Lindane and selected soil properties compiled from the literature. 172

A16 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Linuron and selected soil properties compiled from the literature. 173

A17 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Malathion and selected soil properties compiled from the literature. 175

A18 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Methyl Parathion and selected soil properties compiled from the literature 176

A19 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Methyl Urea and selected soil properties compiled from the literature. 176

A20 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Metobromuron and selected soil properties compiled from the literature. .177

A21 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Monolinuron and selected soil properties compiled from the literature. 178

A22 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Neburon and selected soil properties compiled from the literature. 179

A23 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for p-Chloroaniline and selected soil properties compiled from the literature . .179

A24 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Parathion and selected soil properties compiled from the literature. 180

A25 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Phenyl Urea and selected soil properties compiled from the literature. 180

A26 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Picloram and selected soil properties compiled from the literature. 181

A27 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Promethone and selected soil properties compiled from the literature. 182

A28 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Prometryne and selected soil properties compiled from the literature. 183

A29 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Propazine and selected soil properties compiled from the literature. 185

A30 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Simazine and selected soil properties compiled from the literature. 187

No. Page

A31 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Terbacil and selected soil properties compiled from the literature. 193

A32 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Thimet and selected soil properties compiled from the literature. 193

A33 Adsorption Isotherm Parameters (K, N, K_D and Koc) for trans-telone and selected soil properties compiled from the literature. 194

A34 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Trithion and selected soil properties compiled from the literature. 194

A35 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for 2,4-D acid and selected soil properties compiled from the literature. 195

A36 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for 2,4-D amine and selected soil properties compiled from the literature. 196

A37 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for 2,4,5-T and selected soil properties compiled from the literature. 196

A38 Adsorption Isotherm Parameters (K, N, K_D and K_{OC}) for Denobil and selected soil properties compiled from the literature. 197

A39 Article Number used in Tables A1-38 and the corresponding literature citation 199

B1 Solvent extractable 2,4-D disappearance rates in laboratory incubated soils under aerobic conditions 201

B2 Solvent extractable 2,4-D disappearance in the field 202

B3 Mineralization rates of ^{14}C-ring labeled 2,4-D in soils under aerobic conditions 203

B4 Solvent extractable 2,4,5-T disappearance rates in soils incubated in the laboratory under aerobic conditions 204

B5 Solvent extractable 2,4,5-T disppearance rates under field conditions 205

B6 Solvent extractable atrazine disappearance rates under field conditions 206

B7 Solvent extractable simazine disappearance rates in the field . .207

B8 Solvent extractable atrazine disappearance rates in soils incubated in the laboratory under aerobic conditions 208

No. Page

B9 Solvent extractable simazine disappearance rates in soils under aerobic laboratory incubation 209

B10 Mineralization rates in soils from ring-labeled ^{14}C-atrazine under aerobic conditions 210

B11 Solvent extractable trifluralin disappearance rates in soils incubated in the laboratory under aerobic conditions 211

B12 Solvent extractable trifluralin disappearance rates in soils incubated in the laboratory under anerobic conditions 212

B13 Solvent extractable trifluralin disappearance rates in the field . .213

B14 Solvent extractable bromacil disappearance rates in soils incubated in the laboratory under aerobic conditions 214

B15 Solvent extractable terbacil disappearance rates in soils incubated in the laboratory under aerobic conditions 215

B16 Mineralization for bromacil in soils under aerobic conditions . . .216

B17 Mineralization rates for terbacil in soils under aerobic conditions 217

B18 Solvent extractable bromacil disappearance rates in the field . . .218

B19 Solvent extractable terbacil disappearance rates in the field . . .219

B20 Solvent extractable linuron disappearance rates in soils incubated in the laboratory under aerobic conditions 220

B21 Solvent extractable linuron disappearance rates in the field 221

B22 Solvent extractable diuron disappearance rates in the field 222

B23 Solvent extractable dicamba disappearance rates in soils incubated in the laboratory under aerobic conditions 223

B24 Solvent extractable dicamba disappearance rates in the field 225

B25 Solvent extractable picloram disappearance rates in soils incubated in the laboratory under aerobic conditions 226

B26 Mineralization rates for carboxy-^{14}C-labeled picloram in soils under aerobic conditions 228

B27 Solvent extractable picloram disappearance rates in the field . . .230

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

No. Page

B28 Solvent extractable dalapon disappearance rates in soils under laboratory aerobic incubation 231

B29 Solvent extractable TCA disappearance rates in soils incubated in the laboratory under aerobic conditions 232

B30 Solvent extractable TCA disappearance rates in the field 233

B31 Solvent extractable glyphosate disappearance rates in soil under greenhouse conditions. 234

B32 Mineralization rates for glyphosate in soils incubated in the laboratory under aerobic incubation 235

B33 Solvent extractable parathion disappearance rate in soils under laboratory aerobic incubation 236

B34 Solvent extractable parathion disappearance rates in the flooded soils incubated in the laboratory 237

B35 Solvent extractable parathion disappearance rates in the field . . . 238

B36 Solvent extractable methyl parathion disappearance rates in soils incubated in the laboratory under aerobic conditions 239

B37 Solvent extractable diazinon disappearance rates in soils incubated in the laboratory under aerobic conditions 240

B38 Solvent extractable diazinon disappearance rates in flooded soils incubated in the laboratory 241

B39 Solvent extractable fonofos disappearance rates in the field (complex first-order). 242

B40 Solvent extractable fonofos disappearance rates in the field (simple first-order) 243

B41 Solvent extractable malathion disappearance rates in soils incubated in the laboratory under aerobic conditions 244

B42 Solvent extractable phorate disappearance rates in soils incubated in the laboratory under aerobic conditions 245

B43 Solvent extractable phorate disappearance rates in the field 246

B44 Solvent extractable carbofuran disappearance rates in soils incubated in the laboratory under aerobic conditions 247

B45 Solvent extractable carbofuran disappearance rates in flooded soils 248

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE
6-1/2"
9-1/2"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

No.		Page
B46	Solvent extractable carbofuran disappearance rates in the field . .	249
B47	Mineralization rates of ^{14}C-labeled carbofuran in soils under aerobic conditions	250
B48	Solvent extractable carbaryl disappearance rates in soils incubated in the laboratory under aerobic conditions	251
B49	Solvent extractable carbaryl disappearance rates in the field . . .	252
B50	Solvent extractable DDT disappearance rates in the field	253
B51	Solvent extractable DDT disappearance rates in flooded or anaerobic soils incubated in the laboratory	255
B52	Solvent extractable aldrin and dieldrin disappearance rates in the field	256
B53	Solvent extractable aldrin and dieldrin disappearance rates in soils incubated in the laboratory under aerobic conditions	257
B54	Solvent extractable endrin disappearance rates in the field	258
B55	Solvent extractable endrin disappearance rate in flooded soils under laboratory incubation conditions	259
B56	Solvent extractable chlordane disappearance rates in the field . . .	260
B57	Solvent extractable heptachlor disappearance rates in the field . .	261
B58	Solvent extractable heptachlor disappearance rates in soils under laboratory aerobic incubation	262
B59	Solvent extractable lindane disappearance rates in the field	263
B60	Solvent extractable lindane disappearance rates in soils incubated under aerobic conditions	264
B61	Solvent extractable lindane disappearance rates in flooded soils in laboratory studies	265
B62	Solvent extractable PCP disappearance rates in flooded soils	266
B63	Solvent extractable PCP disappearance rates in soils incubated in the laboratory under aerobic conditions	267
C1	Correlation coefficients between sorption maxima and selected soil properties by Ballaux and Peaslee (1975)	269

No. Page

C2 Correlation coefficients between phosphate sorption parameters and soil properties taken from Vijayachandran and Harter (1975). . . 270

C3 Phosphate sorption correlated with extractable Al and Fe by Williams et al. (1958) 271

C4 Regression equations resulting from correlations of phosphate sorption and Tamm extractable Fe or Al (Williams et al., 1968) . . . 272

C5 Correlation coefficients of phosphate sorption parameters versus physical and chemical properties of the soils, their clay fractions, and bottom sediments used by McCallister and Logan (1958) 273

C6 Correlation and regression coefficients for phosphate sorption and properties for the tropical and British soils (Lopez-Hernand and Buruham, 1974) 274

C7 Correlation coefficients and regression equations between phosphate retention and soil properties for A and B horizons (Sanders, 1965) 275

C8 Regression equations of phosphate retention on aluminum and iron values for soil groups (Saunders, 1965) 276

C9 Correlation coefficients for soil groups between phosphate retention† and aluminum and iron values (Saunders, 1965) 277

C10 Langmuir constants published in literature 278

C11 Description of soils used by Ballaux and Peaslee (1975) 285

C12 Description of soil used by Vijayachandran and Harter (1975) 286

C13 Description of soils used by Syers, et al. (1973) 287

C14 Description of soils used by El-Nennah (1975) 288

C15 Description of soils used by Holford et al. (1974) 289

C16 Description of soils used by Myszka and Janowska (1973) 290

C17 Description of gels used by Rajan and Perrott (1975) 291

C18 Description of gels used by Rajan (1975) 292

C19 Description of limestones used by Holford and Mattingly (1975) . . . 293

C20 Description of soils used by Weir and Soper (1962) 294

No. Page

C21 Description of soils and sediments used by McCallister and Logan (1978) 295

C22 Regression parameters from phosphate adsorption isotherms using $S = S_{max} - \frac{1}{k}\left(\frac{S}{C}\right)$ as the regression model (S_{max} and 1/k) are regression coefficients) 296

C23 Descriptions of soils and experimental parameters used by Minns and Fox (1976) from whose isotherms Langmuir parameters given in Table A3-4 were computed 299

C24 Description of soils and experimental parameters used by Holford and Mattingly (1976) and Russell (1963) from whose isotherms Langmuir parameters were computed 300

C25 Experimental parameters used by Hope and Syers (1976) from whose isotherms Langmuir parameters were computed 301

C26 Experimental parameters used by Singh and Tabatabai (1976) from whose isotherms Langmuir parameters were computed 302

C27 Experimental parameters used by Edzwald et al. (1976) from whose isotherms Langmuir parameters were computed 303

C28 Experimental parameters used by Barrow (1972) from whose isotherms Langmuir parameters were computed 304

C29 Experimental parameters used by Ryden et al. (1977a,b) from whose isotherms Langmuir parameters were computed 305

C30 Experimental parameters used by Ryden and Syers (1975) from whose isotherms Langmuir parameters were computed 306

C31 Data used for calculating Langmuir constants (listed in Table A3-4) from isotherms 309

C32 Freundlich constants found in literature 321

ACKNOWLEDGEMENTS

The authors are indebted to Dr. P. V. Rao, Statistics Department, University of Florida for his assistance in statistical analyses of the data presented in this report. The following members of the Soil Science Department, University of Florida provided technical assistance in data collection and analyses: Mr. R. E. Jessup, Mr. D. P. Kilcrease, Mr. D. Forbes, and Mrs. Rupei-Shu Li. Computer retrieval of the pesticide and phosphorus literature was accomplished with the assistance of Mr. G. T. Kovalik, Hume Library, University of Florida. Expert typing of the draft and final versions of this report was done by Mrs. Katherine B. Williams. Special thanks are extended to Mr. C. N. Smith and Mr. L. A. Mulkey of Environmental Research Laboratory, USEPA, Athens, GA. for over-all project coordination and guidance.

The project investigators wish to express their appreciation to the Center for Environmental Programs in the Institute of Food and Agricultural Sciences, University of Florida for partial financial support during the project period. The project investigators are also indebted to their colleagues in the Department of Soil Science and the Department of Food Science and Human Nutrition, University of Florida for their assistance and suggestions during the development of this report.

TYPING GUIDE SHEET

SECTION 1

INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972, Public Law No. 92-500, specifies that the Administration of the Environmental Protection Agency shall, in cooperation with other agencies, provide guidelines for identifying and evaluating the nature and extent of nonpoint pollution sources. Because fertilizers and pesticides play such a major role in todays agriculture, runoff from fields involved with agricultural production has long been suspect of being a major nonpoint pollution source. Although it is difficult to conceive of a situation in which all possible environmental risks associated with the use of agricultural chemicals could be eliminated, management practices can be used that will significantly reduce these risks. Nonpoint agricultural pollutants of primary concern are sediment, nitrogen, phosphorus, and pesticides. The latter two pollutants can be transported from an agricultural field by both the water and sediment phases.

Several models (stochastic, empirical and deterministic) exist for estimating water and sediment transport from small fields and watersheds. More than 45 years of erosion research by the U.S. Department of Agriculture in cooperation with state agricultural experiment stations has resulted in the development of numerical relationships for estimating annual soil losses from fields. Because of the success of these models and their previous calibration for specific regions, most agricultural chemical transport models were developed by "piggybacking" the components for chemical transport to the hydrologic and sediment transport models. The sediment and agricultural transport models were developed in order to simulate the impact of agricultural production on water quality. The models also have the potential to be used by state and local agencies in developing and/or identifying land use management practices that will provide the least risk to the environment.

Many of the existing chemical transport simulation models have been calibrated to describe the behavior of a given plant nutrient or pesticide at a given location and for a specific cultural system. The feasibility of continuing to calibrate the simulation models for a wide range of chemicals and management practices is not practical. Therefore, general relationships for estimating the basic coefficients required to describe adsorption and transformations of agricultural chemicals in the soil surface region subject to erosion are needed. Also the confidence that can be attached to the independently measured or estimated coefficients used in the chemical transport models for describing adsorption and transformation processes must be quantified.

EPA-287 (Cin.)
(4-76)

Numerous equilibrium adsorption studies have been conducted using various pesticides and phosphorus sources as well as different soils. The validity of the equilibrium adsorption assumption based on relatively short term experiments (less than 72 hours) and the reversibility of the adsorption-desorption process has been questioned by several researchers. Adsorption associated with short term laboratory experiments may not be relevant for the long contact periods encountered under natural field conditions. Also, recent experiments involving "bound" pesticide residues point out the problem associated with assuming reversible adsorption, especially that occuring during sediment and water transport from an agricultural field or watershed. The bound pesticide residue question suggests that some of the pesticide transformation or disappearance data available in the literature may be in error and not suitable for estimating transformation rate coefficients of the original parent compound.

The primary emphasis of the present report will be to present an extensive and reliable data base of the principal coefficients for describing adsorption and transformation characteristics of phosphorus and a broad spectrum of pesticides used across a range of soil types. This information was obtained from an extensive literature search using various computer information retrieval packages (data banks such as CANE, BIOSIS, etc.). The dependence of these retention and transformation coefficients on selected soil properties was evaluated. The information presented in this report would be helpful in estimating the values of the retention and transformation parameters required in various non-point source pollution models.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

SECTION 2

CONCLUSIONS

1. A large data base exists for estimating partition coefficients for pesticide retention in soils. An analysis of these data indicated that errors associated various simplifying assumptions (e.g., linear and singular isotherms; instantaneous equilibrium) appear to be within a factor of 2 or 3. Such errors may be tolerable for most nonpoint source pollution modeling applications.

2. For a given pesticide, adsorption partition coefficients based on soil organic carbon were fairly constant regardless of soil type. Furthermore, octanol-water partition coefficients were good predictors of pesticide adsorption partition coefficients.

3. Persistence in soils of a large number of pesticides under a broad range of soil environmental condition has been reported. A data base was compiled for first-order decay constants (k) and half-lives ($t_{1/2}$) for pesticide disappearance in soils.

   Over the wide range in soil and environmental conditions under which degradation was measured, the coefficient of variation of the average k and $t_{1/2}$ values for a given pesticide was surprisingly small (<100%). Thus, pesticide disappearance rates can be estimated within a factor of 2 to 4 for most pesticides using presently available data.

4. In most cases, half-lives of pesticides under field conditions are shorter than those under laboratory incubation studies. This was attributed to the fact that under field conditions a multitude of factors and processes contribute to pesticide disappearance, while laboratory studies are performed under controlled conditions and measure a single process.

5. Efforts to develop multiple regression equations correlating degradation rates with soil properties were unsuccessful. Part of the problem arises in that many reports reviewed failed to give soil physico-chemical properties and incubation conditions (temperature and soil-water tension).

6. Pesticides were placed into the following three groups based upon their half-lives in soils: non-presistent ($t_{1/2} \leq 20$ days), moderately persistent ($20 < t_{1/2} < 100$ days), and persistent ($t_{1/2} \geq 100$ days). Pesticides in the first group are 2,4-D, 2,4,5-T, dicamba, parathion, methyl parathion, and malathion. Moderately persistent pesticides are atrazine, simazine, trifluralin, diuron, terbacil, carbaryl, and carbofuran. Most chlorinated hydrocarbon pesticides were grouped as persistent.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

7. Formation of "bound pesticide residues" confounds the problem of estimating pesticide degradation rates. Differentiation must be made between the rate constants for (i) disappearance of parent compound and (ii) pesticide mineralization. The first rate constant does not take into account formation of bound residues or accumulation of metabolites, while the second rate constant represents a total breakdown of the pesticide molecule. Therefore, half-lives based on parent compound disappearance are generally larger than those based on pesticide mineralization.

8. Seasonal pesticide losses by runoff from agricultural fields, in general, are less than 0.5% of the amount applied. Although pesticide concentrations in the sediment-phase are larger than those in the solution-phase, pesticide carried in the water accounts for >90% of the total loss for a given runoff event; exceptions to this generalization are highly sorbed pesticides (e.g., diquat, chlorinated hydrocarbons) and runoff with high sediment loads.

9. A broad range of Langmuir isotherm parameters were compiled for phosphate sorption by soils and other solid adsorbents. Based upon limited amount of data available, the sorption parameters were found to be significantly correlated with extractable ("active") Fe and Al.

10. A lack of uniformity in experimental methods used in determining the Langmuir sorption parameters or phosphate sorption indices was noted. Development of standardized methodology (or protocols) for this purpose appears to be essential for quantification of phosphate sorption parameters.

11. "Active" Fe and Al appear to be measured by oxalate extraction rather than by citrate-dithionite-bicarbonate extraction. Crystallinity of Fe and Al oxyhydroxides play a dominant role in determining inorganic phosphate sorption.

12. A "universal" partition function for inorganic phosphorus retention in soils can be developed provided proper input parameters are measured. These parameters include the measurement of "active" Fe and Al, time-dependence of phosphate adsorption-desorption, and phosphate sorption isotherm parameters.

SECTION 3

RECOMMENDATIONS

1. Measurement of octanol-water partition coefficients for a broad spectrum of pesticides should be continued. Special emphasis should be given to recently developed high-pressure liquid chromatography (HPLC) methods for estimating octanol-water partition coefficients. Also, this concept should be extended for ionic and ionizable organic compounds.

2. Further evaluation of factors responsible for the measured nonsingularity in pesticide adsorption-desorption isotherms is essential.

3. The relative contributions of various particle-size fractions of soils to pesticide retention should be measured. Such data are now available only for a limited number of organic compounds and not for a wide-range of soil pesticide combinations. This information will be used to evaluate the significance of runoff sediment "enrichment" by fines in estimating total pesticide losses.

4. The disappearance rate of solvent-extractable parent compound should not be used as the only measure of pesticide degradation rate in soil-water systems. The potential for significant accumulations of toxic metabolites (specially under anaerobic conditions) and formation of "Bound residues" must be taken into account.

5. Mineralization rate (i.e., total breakdown of pesticides to carbon dioxide, water, and inorganic ions) should be used as index of pesticide degradation rate because it represents total detoxification of the pesticide. Because mineralization rates are generally smaller than parent compound disappearance rates, the former provides a more conservative estimate of the pesticide degradation rate.

6. The rates and mechanisms of bound pesticide residue formation in soils as well as the release characteristics and environmental toxicity of these residues should be characterized. Special attention should also be given to rates of formation and release of bound residues under anaerobic environments (encountered by sediment-bound pesticide residues in streams, rivers, lakes, etc.)

7. Empirical regression equations are needed for describing the dependence of pesticide degradation rates on soil environmental variables (temperature and soil-water content or potential) in order to estimate degradation rates for a given pesticide in various soils under several environmental conditions.

8. Simple experimental methods for measuring and/or estimating pesticide degradation rates should be developed.

9. Standardized methodology (protocols) should be developed for measuring phosphate sorption parameters, "active" soil components (Fe and Al oxyhydroxides and solubilized Ca) involved in phosphate retention, and the time-dependence of phosphate sorption-release in soil-water systems.

10. Further testing of various phosphate sorption models is required in order to develop appropriate sorption parameters.

11. A quantitative index needs to be defined for the "crystallinity" of the Fe and Al oxyhydroxides in soils. Such an index will be used in developing a "universal" partition function for phosphate retention by soils, in concept to pesticide partition coefficients based on soil organic carbon.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

SECTION 4

RETENTION OF PESTICIDES IN SOILS

P.S.C. Rao and J.M. Davidson

METHODS FOR MEASURING PESTICIDE RETENTION

Over the past two decades a number of experimental methods were proposed for measuring pesticide adsorption-desorption in soil-water systems. The basic objective of all these methods has been to measure the relationship at equilibrium between the pesticide solution and adsorbed phase concentrations. Based upon the manner in which equilibrium between the adsorbent and the adsorbate is achieved, the adsorption methods can be grouped under "batch-equilibrium" or "flow-equilibrium" methods. Within each group, several methods with minor variations can be found. Because of their simplicity, the batch methods are most widely used, while the flow methods have not received equal attention.

In the batch methods, a known weight (m,g) of air-dry soil is suspended in a pesticide solution of known volume (V,ml) and initial concentration (C_i, μg/ml). This suspension is agitated for a pre-determined time (from 1 hr to 48 hrs) and the solution pesticide concentration (C_e, μg/ml) is determined after filtration or centrifigation (speeds ranging from 500 G to 60,000 G) to obtain a clear supernatent solution. Any change in solution concentration (i.e., $\Delta C = C_i - C_e$) is attributed to adsorption on the soil. Therefore, the adsorbed phase concentration (S_e, μg/g soil) at equilibrium is calculated as follows:

$$S_e = (V/m)\,(\Delta C) \qquad [4\text{-}1]$$

Measurement of S_e at several values of C_e then yields the adsorption isotherm. An alternate, but less common, procedure is the direct determination of the adsorbed-phase concentration by extraction of the soil with appropriate organic solvents. In another variation of the batch method, the soil and solution phases were separated during equilibration by a semi-permiable membrane such as dialysis tubing or colloidon membrane (Bailey and White, 1964; Hayes et al., 1968).

In the flow-equilibration methods, pesticide solution of known concentrations (C_o, μg/ml) is continually passed through a "flow cell" in which a known weight of soil is either maintained in suspension (Grice and Hayes, 1972; Grice et al., 1973) or is packed as a thin pad (Green and Corey, 1972; Burchill et al., 1973). A series of small volume fractions of the effluent solution are collected and the pesticide concentrations in each of these fractions

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

is determined. A plot is then made of the effluent concentration (C_n) in each fraction versus cumulative effluent volume (V_n). By assuming that instantaneous equilibrium is achieved between the solution and the adsorbed phases during displacement through the flow cell, the amount adsorbed can be calculated:

$$mS_n = C_o V_n - V_c C_n - \int_o^{V_n} C \, dV \qquad [4\text{-}2]$$

where, S_n = adsorbed concentration (μg/g), C_o = input concentration (μg/ml), V_n = cumulative effluent volume (ml), C_n = effluent concentration (μg/ml) at V_n, V_e = solution volume in the flow cell, and m = weight of soil in the flow cell. Note that in Eq. [4-2], the three terms on the r.h.s. represent, respectively, total amount of pesticide in input in solution within flow cell, and total outflow. By performing the above calculation at selected values of V_n or C_n, the flow cell method yields several S vs. C values from a single displacement experiment. Unfortunately, the assumption of instantaneous equilibrium is not necessarily satisfied for all soil-pesticide combinations. In fact, a similar flow cell technique was used to measure the kinetics of adsorption-desorption reactions in soils.

In the flow-through method proposed by Green and Corey (1971) a pesticide solution of known concentration (C_o) was displaced through a thin pad of soil until inflow and outflow concentrations were equal. The total amount of (T) pesticide adsorbed by the soil and that in the solution in the soil pad were quantitatively extracted by a suitable organic solvent and measured. The amount of pesticide adsorbed (S) by the soil was computed as:

$$S = \frac{1}{m} [T - VC_o] \qquad [4\text{-}3]$$

where, V is the volume of solution (ml) retained by the soil pad. This method is superior to other flow methods because (i) no assumptions regarding adsorption kinetics are involved, and (ii) increases precision because the amount adsorbed is directly quantified in contrast to batch methods. However, like the batch method, the flow method yields only one adsorption value, the S value associated with C_o. Thus, several soil pads exposed to a range of C_o values are required for determination of an adsorption isotherm.

The degree of success and acceptance of a given method depends primarily upon (i) the specific pesticide-soil combination, (ii) the ease with which large numbers of measurements may be performed, (iii) the intended application of adsorption data, and (iv) the precision of measurement. Green et al. (1976) present an excellent review of the above methods. They concluded that although the flow-equilibration methods offered obvious advantages (increased precision, maintaining the soil structure), batch methods will continue to be extensively used because of their simplicity. The batch method, in fact, is specified in the "Protocol for Adsorption Tests" published by the U.S. Environmental Protection Agency (1975).

ADSORPTION ISOTHERM MODELS

Various mathematical relationships have been used to describe equilibrium pesticide adsorption-desorption in soil-water systems. Among the more

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

successful are the Freundlich and Langmuir equations. The Freundlich equation is stated as:

$$S = KC^N \qquad [4\text{-}4]$$

where, S = amount pesticide adsorbed (μg/g soil), C = solution-phase pesticide concentration (μg/ml), and K and N are empirical coefficients that depend on the soil-pesticide system. Taking natural logarithms of both sides of Eq.[4-4] yields,

$$\ln S = \ln K + N \ln C. \qquad [4\text{-}5]$$

Thus, the coefficients K and N may be obtained, respectively, as the intercept and slope of log-log plots of S versus C. The Langmuir equation may be stated as

$$S = \frac{S_{max}\, k\, C}{1 + k\, C} \qquad [4\text{-}6]$$

where, S_{max} = maximum adsorption capacity (μg/g soil), k = Langmuir coefficient related to adsorption bonding energy (ml/μg), and S and C are as defined earlier. The more commonly used linear form of the Langmuir equation is,

$$\frac{C}{S} = \frac{1}{k\, S_{max}} + \frac{1}{C\, S_{max}} \qquad [4\text{-}7]$$

It is evident from Eq. [4-7] that from a plot of C/S versus 1/C, the coefficients k and S_{max} can be calculated.

The Langmuir model was originally developed to describe adsorption of gases on homogeneous surfaces. Three important assumptions made in deriving Eq. [4-6] are (i) the energy of adsorption is the same for all sites and is independent of degree of surface coverage, (ii) adsorption occurs only on localized "sites," with no interaction between adjoining adsorbed molecules, and (iii) the adsorption maximum (S_{max}) represents a monolayer coverage. Given these fairly restrictive assumptions, it is not surprising that the Langmuir equation generally fails to describe pesticide adsorption in such a complex and heterogeneous media as soils. The ability of the Freundlich equation to describe pesticide adsorption on soils, both at low and high concentrations, is well-documented (Hamaker and Thompson, 1972; Davidson et al., 1978; Rao and Davidson, 1979). Although it is generally suggested that the Freundlich equation has no conceptual basis, Eq. [4-4] can be derived from the Langmuir equation if the energy of adsorption is assumed to decrease with increasing surface coverage (Thomas and Thomas, 1967).

For solution concentrations similar to those associated with agricultural eco-systems, Eqs. [4-4] and [4-6] may be assumed to be linear,

$$S = K_D\, C \qquad [4\text{-}8]$$

when N = 1 in Eq. [4-4] and when kC<<1 in Eq. [4-6]. The K_D value has units of ml/g and is commonly referred to as the adsorption partition coefficient.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

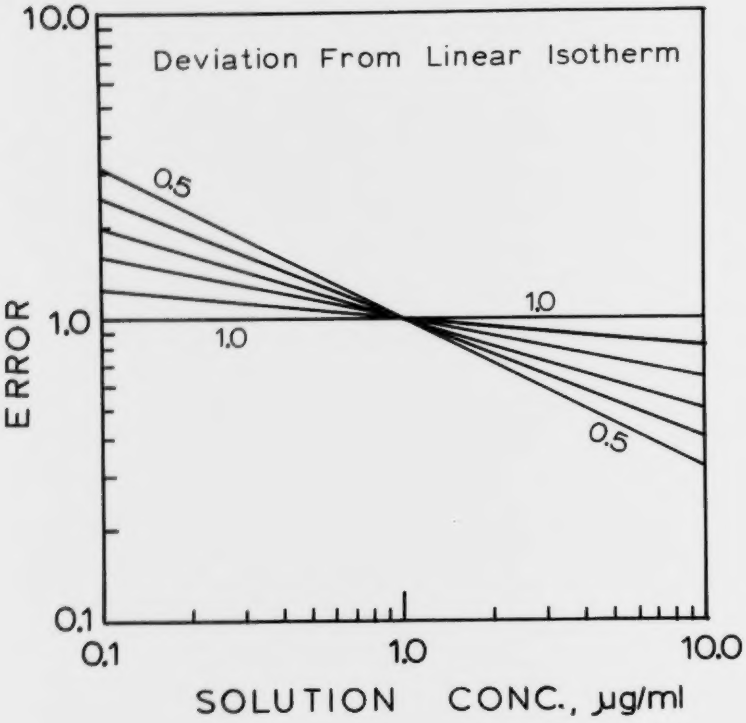


FIGURE 4-1. Graphical representation of the error introduced by the assumption of linearity when the adsorption isotherms are nonlinear. The numbers on the lines are the values of Freundlich constants N (see Eq. 4-4 and 4-8).

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-78)

The error introduced by assuming the adsorption isotherm to be linear depends upon the values of C and N. This error can be represented as the ratio of Eq. [4-4] and Eq. [4-8] and is equal to C^{N-1}. A plot of C^{N-1} versus C in the range of 0.1 to 10 μg/ml and for N values ranging from 0.5 to 1.0 is shown in Figure 4-1. It may be noted that an error factor of 1.0 represents perfect agreement between linear and nonlinear isotherms. Thus, for $C < 1.0$, the amount adsorbed in under-predicted, while for $C > 1.0$, the amount adsorbed is over-predicted by assuming linearity. However, for $0.1 < C < 10.0$ and $0.5 < N < 1.0$, as shown in Figure 4-1, the maximum deviation will be by a factor of 3, if Eq. [4-8] was used instead of Eq. [4-4]. Such errors may be tolerable for many practical applications as in nonpoint source pollution models. However, for large solution concentrations, such as those encountered under pesticide waste disposal sites, the amount adsorbed could easily be over-estimated by an order of magnitude or more (Davidson et al., 1978; Rao and Davidson, 1979).

TIME DEPENDENCE OF ADSORPTION-DESORPTION

A majority of the literature deals with the partitioning of pesticides at equilibrium between the soil and solution phases while a very few researchers have investigated the rate at which equilibrium is achieved. Under conditions of steady or transient water flow in soils, sufficient time may not be available to achieve instantaneous local equilibrium for pesticide adsorption-desorption. Consequently, many investigators studying pesticide movement have had to measure the kinetics of the adsorption-desorption processes.

The amount of pesticide adsorbed with time was assumed to follow reversible non-linear kinetics to yield the following rate expression (Van Genuchten et al., 1974):

$$\frac{\partial S}{\partial t} = k_2 \ [(\frac{k_1\Theta}{k_2\rho}) \ C^N - S] \qquad [4\text{-}9]$$

where, k_1 and k_2 are, respectively, the kinetic rate coefficients (hr^{-1}) for forward and backward reactions, Θ is soil-water content (cm^3/cm^3), ρ is soil bulk density (g/cm^3), t is time (hr), and C and S are as defined previously. Note that at equilibrium (i.e., $\partial S/\partial t = 0$), Eg. [4-9] reduces to Eq. [4-4] with the Freundlich coefficient K equal to $(\Theta k_1/\rho k_2)$. Lapidus and Amundson (1952) and Oddson et al. (1970) used Eq. [4-9] with N = 1, which describes reversible first-order processes leading to a linear isotherm at equilibrium.

A detailed study of 2,4-D herbicide adsorption kinetics on three clay minerals (illite, kaolinite, and montmorillonite) was reported by Haque et al. (1968). The rate expression used by these authors was:

$$\frac{d}{dt}(1 - \Phi) = k' \ (1 - \Phi) \qquad [4\text{-}10]$$

where, $\Phi = q_t/q_e$, q_t is amount adsorbed (μg/g) at time t (hrs), q_e is amount adsorbed at equilibrium ($t \to \infty$), and k' is the adsorption rate constant (hr^{-1}). Note that in Eq. [4-10], the rate of adsorption is proportional to the distance from equilibrium. In deriving Eq. [4-10], it was assumed that the reverse reaction, the desorption rate, was small enough to be neglected. This assumption was satisfied by using large amounts of clay (reactive surface available for adsorption) and low 2,4-D solution concentration. Further refinements to Eq. [4-10] were made by accounting for the change in free energy of activation with surface coverage. The calculated values for k' ranged from 1.98 X 10^{-3} to 7.88 X 10^{-3} hr^{-1}. The k' value was shown to decrease nonlinearly with increasing clay surface area and decreasing temperature. Hague et al. (1968) concluded that the rate-limiting step in adsorption was diffusion to the reactive sites within the clay matrix and not the kinetics of reaction at the site.

Lindstrom et al. (1970) proposed a model for the kinetics of adsorption-desorption processes. Their model was an extension of an earlier model derived by Fava and Eyring (1956) who considered only adsorption. A second improvement incorporated by Lindstrom et al. was that the "sticking probability" (Langmuir, 1918) for the adsorbate on the adsorbent surface was allowed to vary with degree of surface coverage. Their model also allowed for adsorption and desorption energies to change with surface coverage. This model may be stated as

$$\frac{\partial S}{\partial t} = [k_2 \exp (\beta S)] \quad [(\frac{k_1 \Theta}{k_2 \rho}) C \exp (-2\beta S) - S] \qquad [4\text{-}11]$$

where, β is similar to the surface stress coefficient described by Fava and Eyring (1956), and other parameters are as defined for Eq. [4-9]. For equilibrium conditions ($\partial S/\partial t = 0$), Eq. [4-11] reduces to:

$$S = [\frac{\Theta k_1}{\rho k_2}] [C \exp (-2\beta S)]. \qquad [4\text{-}12]$$

The above equation may be rearranged as

$$\ln (S/S) = \ln (\frac{\Theta k_1}{\rho k_2}) - 2\beta S \qquad [4\text{-}13]$$

Therefore, the parameters β and $(\theta k_1/\rho k_2)$ may be evaluated from the slope and intercept, respectively, of plots of ln (S/C) versus S for various equilibrium solution concentrations. The usefulness of Eqs. [4-12] and [4-13] for describing picloram movement in saturated soil columns was evaluated by van Genuchten et al. (1974). They found that both kinetic models described measured data reasonably well at low pore-water velocities, but not at large velocities.

The conceptual models described above are valid for homogeneous surfaces because a single adsorption mechanism or a single type of adsorption site is assumed to be responsible for adsorption. In soils, a variety of reactive components exist and this assumption may not be valid. For instance each reactive component of the soil (e.g., organic matter, clay minerals, etc.) may provide different adsorption sites which vary in energies and kinetics of adsorption-desorption. A further complicating factor is that not all adsorption sites may be equally accessible. Leenheer and Ahlrich (1971) reported that although 60% of the reaction was completed in only 1 minute,

TYPING GUIDE SHEET

adsorption of carbaryl and parathion on organic matter continued at a slow rate for another 2 to 3 hours. These authors suggested that the rate-limiting step for times greater than 1 to 2 minutes was pesticide diffusion to adsorption sites in the interior of the organic matter. Similar observations of initial rapid reaction followed by a slow reaction over long times have been reported by several authors (Hamaker et al., 1966; Weber and Gould, 1966; Wahid and Sethunathan, 1978).

NON-SINGULARITY OF ADSORPTION-DESORPTION

The implicit assumption made in most adsorption studies is that adsorption-desorption have the same characteristics and that Eqs. [4-4] - [4-8] can be used to describe both adsorption and desorption isotherms. However, recent research indicates that for several soil-pesticide systems, the adsorption-desorption processes may be non-singular and perhaps may even be irreversible. Non-singularity is said to exist when, for a given equilibrium solution concentration, more pesticide is retained on the soil during the desorption phase than during the adsorption phase. Some of the early data in this regard was presented by Swanson and Dutt (1973) and Hornsby and Davidson (1973). Similar results for a large number of soil-pesticide systems have been reported (van Genuchten et al., 1974; Rao, 1974; Farmer and Aochi, 1974; Murray et al., 1975; Peck, 1977). In spite of considerable research, in this area, the physical-chemical basis for the experimentally measured non-singularity remains unclear at the present time. Mukhtar (1976) conducted a comprehensive study to examine the relationship between non-singularity and the mechanisms, kinetics, and energies of adsorption-desorption processes. He found that the degree of non-singularity was directly proportional to the amount adsorbed prior to initiation of desorption, the rate of adsorption, and the adsorption energy. Mukhtar (1976) also presents an excellent review of related work.

Based upon the observations reported, three major causes for the non-singularity may be identified: (i) artifacts created due to some aspect of the method, (ii) failure to establish complete equilibrium during adsorption phase, and (iii) chemical and/or microbial transformations of the pesticide during the course of the experiment. Each of these factors is discussed below in detail.

Common to all studies dealing with non-singularity is the batch equilibrium method. The adsorption isotherm points are measured as described in an earlier section. Desorption is initiated by centrifuging the "equilibrated" soil-pesticide systems, removing a known volume of pesticide solution, replacing with an equal volume of pesticide-free solution, and resuspending the soil-pesticide solution. The procedure is repeated to develop desorption isotherms initiated from a point on the adsorption isotherm. This procedure then involves repeated centrifugation and resuspension of the soil followed by prolonged (up to 24 hours for each step) agitation. Such a treatment could cause a breakdown of the soil particles, thus increasing the number of adsorption sites during the desorption phase of the experiment (Savage and Wauchope, 1974). A slow solvent action of the aqueous solution could also unmask new adsorption sites and increase the sites available pesticide adsorption (Hance, 1967). However, both these factors were found not to be

EPA-287 (Cin.)
(4-76)

significant in some experiments (Mukhtar, 1974; Rao and Davidson, 1980). Diuron herbicide adsorption isotherms for soils subjected to a 30-minute sonication pre-treatment were the same as those for unsonicated soils (Mukhtar, 1974). Sonication was expected to be a much harsher treatment and as a result breakdown the soil structure more than agitation or tumbling which is commonly employed. Identical pesticide adsorption isotherms were obtained for soils samples with and without a pre-treatment which consisted of prolonged tumbling (up to 3 days) with centrifugation and resuspension once each day (Rao and Davidson, 1980).

Rao et al. (1978) investigated the possibility that the centrifugation-resuspension step in the batch method might be inducing the observed non-singularity. These authors measured adsorption-desorption isotherms for several soil-pesticide systems using the batch method as described earlier and two modifications of the batch method. Modifications were designed to eliminate the centrifugation step and were: (i) a water-immiscible organic solvent as a third phase to desorb the pesticide from the soil and aqueous phases (3-phase method), and (ii) desorption by dilution of the soil-water-pesticide system (Dilution method). For all soil-pesticide combinations studied, nonsingular adsorption-desorption isotherms were obtained using the "standard" batch method. The adsorption-desorption isotherms measured, using the modified batch method, were nonsingular for certain soil-pesticide combinations. Rao et al. (1978) concluded that the pesticide adsorption mechanism played an important role in determining whether centrifugation induced non-singularity. These authors recommended that the dilution method rather than the "standard" batch method be routinely used for measuring adsorption-desorption isotherms. The reasons as to why centrifugation induces non-singularity are unknown at the present time and further experiments are needed in this regard.

Failure to establish complete equilibrium between the soil and pesticide prior to initiation of desorption has been cited as another cause of non-singularity (Snoeyinketal, 1969). Diffusion-controlled migration of pesticide to adsorption sites within the soil organic matter and/or clay matrix would result in a psuedo-equilibrium (Hance, 1969; Adamson, 1967; Rao et al. 1979). Based on such conceptualization, Selim et al. (1976) proposed a two-site model for adsorption-desorption. Using this model, they were able to simulate non-singularity when desorption was initiated prior to when adsorption equilibrium was attained.

Chemical and microbiological transformations of the pesticide during the course of the experiment have also been suggested to cause the apparent non-singularity in pesticide adsorption-desorption isotherms. Hamaker and Thompson (1972) postulated that a portion of the adsorbed pesticide is held stronger than the remainder and that this fraction tends to increase with time. They also suggest that wetting and drying the soil may enhance this effect. Knight et al. (1970) observed that diquat and paraquat undergo slight rearrangement with time and become more difficult to desorb from a soil. Cheng et al. (1979) demonstrated that a significant portion of the non-singularity observed in 2,4,5-Tisotherms could be explained by accounting for microbial degradation of the parent compound. It is not a common practice to sterilize or to add antibiotics to minimize the microbial activity in

TYPING GUIDE SHEET

soils during the adsorption experiments. However, microbial degradation will not be a significant factor for the more persistent pesticides. Chemical transformations, such as surface-catalyzed hydrolysis of s-triazine herbicides, may also have similar effects as microbial degradation. This aspect has not been thoroughly investigated.

A critical evaluation of the existing literature, which includes many conflicting reports, indicates that while non-singularity of pesticide adsorption-desorption isotherms may often be an artifact, it could be real and significant for certain compounds. Furthermore, under field conditions which involve long contact times between the soil and pesticide, several of the factors discussed earlier operating simultaneously could become significant and lead to an apparent non-singularity. Therefore, it is important to assess quantitatively the errors introduced by not accounting for non-singularity.

As indicated earlier, for non-singular isotherms, the Freundlich coefficients in Eq. [4-4] are different for adsorption and desorption. Thus,

$$S_a = K_a C^{N_a} \qquad [4\text{-}14]$$

$$S_d = K_d C^{N_d} \qquad [4\text{-}15]$$

where, the subscripts a and d denote, respectively, the adsorption and desorption isotherms. Van Genuchten et al. (1974) among others, have shown that the degree of non-singularity is dependent on the maximum amount adsorbed (S_m) before initiation of desorption. This relationship was expressed as

$$K_d = K_a^{\beta} \; S_m^{1-\beta} \qquad [4\text{-}16]$$

where, $\beta = N_d/N_a$. Eq. [4-16] can be restated in terms of the maximum solution concentration (C_m) prior to desorption as

$$K_d = K_a \; C_m^{N_a - N_d} \qquad [4\text{-}17]$$

Substitution of Eq. [4-17] for K_d in Eq. [4-15] yields,

$$S_d = K_a C_m^{N_a - N_d} \; C^{N_d} \qquad [4\text{-}18]$$

The ratio S_d/S_a may be calculated by dividing Eq. [4-18] with Eq. [4-14] as follows

$$\frac{S_d}{S_a} = (C_m^{N_a - N_d}) \; (C^{N_d - N_a}) \qquad [4\text{-}19]$$

Note that the ratio (S_d/S_a) in Eq. [4-19] is equal to 1.0 when $C = C_m$, the point where desorption is initiated, or when $N_a = N_d$, i.e., when the isotherms

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

are singular. Van Genuchten et al. and others have shown that the value of N_d was related to N_a and S_m; however, an average value of $\beta = 1/2{\cdot}3$ was found to be satisfactory (i.e., $N_a = 2.3\ N_d$). Using this relationship in Eq. [4-19] gives

$$\frac{S_d}{S_a} = C_m^{0.5652N_a}\ C^{-0.5652N_a} \qquad [4\text{-}20]$$

A further simplification of Eq. [4-20] is possible, if it is assumed that 10 μg/ml is the largest value of C_m under normal agricultural field conditions. Thus,

$$\frac{S_d}{S_a} = (10^{0.5652N_a})\ (C^{-0.5652N_a}) \qquad [4\text{-}21]$$

The assumption that C_m = 10 μg/ml is useful for illustrating errors introduced when non-singularity is not taken into account. The relationship between S_d/S_a and C, given by Eq. [4-21], is presented graphically in Fig. 4-2 for C_m = 10 μg/ml and several N_a values that cover the range of measured values for a broad spectrum of pesticides. Similar curves can be generated for any other value of C_m using Eq. [4-20]. As evident in Fig. 4-2, the error (i.e., the ratio S_d/S_a) is greater at low solution concentrations and decreases with increasing nonlinearity (N_a<1) of the adsorption isotherm. Therefore, underprediction of the amount remaining adsorbed on the soil during the desorption phase would be more serious for low solution concentrations for linear isotherms. If a factor of 2 or 3 is considered tolerable, then over a solution concentration range of 0.4 to 10 μg/ml the effects of nonsingularity may be ignored.

ESTIMATION OF ADSORPTION PARTITION COEFFICIENTS

Influence of Soil Organic Carbon

The extent to which a pesticide is adsorbed by a soil is determined by several physical and chemical properties of both the soil and the pesticide. Early workers (Sheets et al., 1962; Harris and Sheets, 1965; Bowman et al., 1965; Day et al., 1968; Koren et al., 1969; Liu et al., 1970) attempted to correlate selected soil properties to pesticide adsorption on soils or pesticide biological activity in soils. More recent workers (Savage and Wauchape, 1974; Hance, 1976; van Bladel and Moreole, 1976) have correlated, with varying degree of success, the Freundlich adsorption coefficients (K and N) to selected soil properties such as organic matter content, clay content, and soil pH. These regression equations were developed by measuring adsorption isotherms for a given pesticide and a broad spectrum of soil types. The objective of these regression equations was to estimate the adsorption isotherm parameters (K and N) for other soils given only the input values for independent variables in the regression model.

Most researchers (Hamaker et al., 1966; Savage and Wauchape, 1974; Sheets et al., 1962; Sherbourne and Freed, 1954; Roberts and Wilson, 1965) concluded

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA. OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

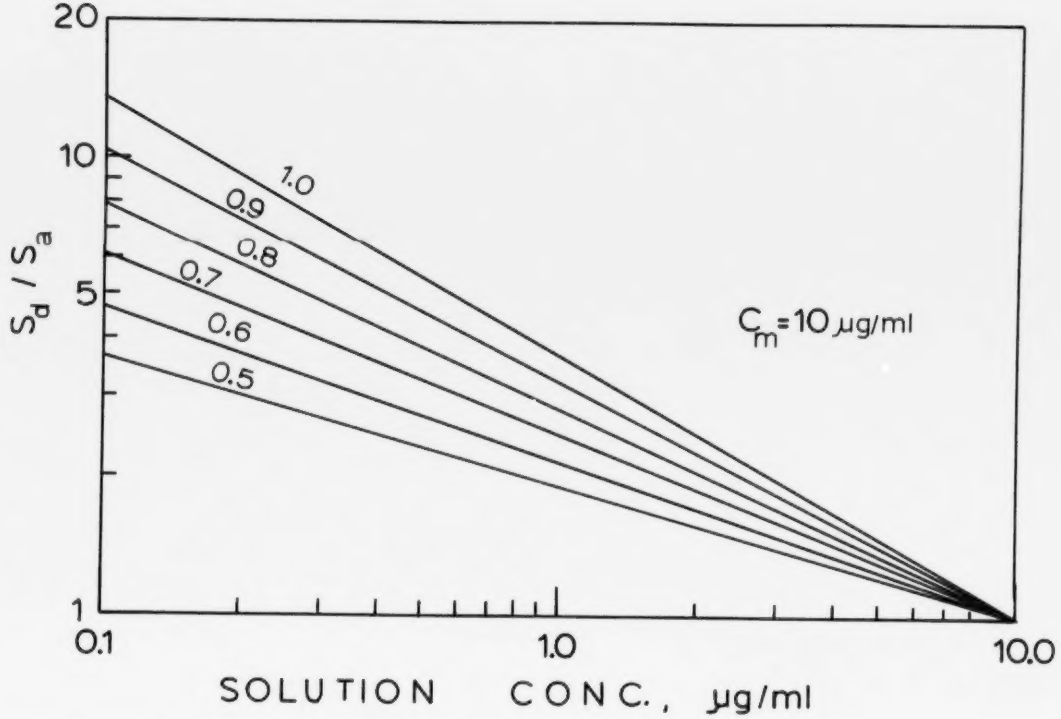


FIGURE 4-2. Errors introduced by the assumption that adsorption-desorption isotherms are singular when they are non-singular (see Eq. 4-20, 4-21).

that soil organic matter content was the single best predictor of the adsorption isotherm parameters. Based on such results, Lambert et al. (1965) have assumed that soil organic matter was the only soil constituent responsible for pesticide adsorption. They proposed the use of an adsorption partition coefficient (K_{om}),

$$K_{om} = \frac{S_{om}}{C} \qquad [4\text{-}22]$$

where S_{om} is the quantity of pesticide (μg) adsorbed per gram of soil organic matter and C is the corresponding solution concentration (μg/ml) Lambert et al. (1965) obtained nearly constant K_{om} values for monuron adsorption for several soils ranging in organic matter content from 1.5 to 4.8%. Organic matter content was calculated by multiplying the experimentally determined value of organic carbon content by a conversion factor. Because various authors have used different conversion factors (ranging from 1.7 to 2.0), Hamaker and Thompson (1972) recommended that soil organic carbon content be used to normalize pesticide adsorption partition coefficients. This parameter, denoted as K_{OC}, is equal to:

$$K_{oc} = \frac{\mu\text{g adsorbed/gm organic carbon}}{\mu\text{g/ml solution}} \qquad [4\text{-}23]$$

Note that from Eq. [4-23],

$$K_{oc} = \frac{(K_D)\ (100)}{\%OC} \qquad [4\text{-}24]$$

where %OC is the organic carbon content of the soil, and K_D is the adsorption partition coefficient.

In deriving Eq. [4-24], it was assumed the K_D is linearly proportional to %OC. For high %OC combined with low clay content, the organic matter may be "piled up" resulting in less available adsorptive surface per unit weight of OC (Hamaker et al., 1966). Similarly, for low OC contents, the "efficiency" of OC appears to increase (Lambert et al., 1965; Hilton and Yuen, 1963; Walker and Crawford, 1968; Shin et al., 1970). The variability in K_{OC} values for a given pesticide was suggested to be due to the differences in "efficiency" of the soil organic carbon among soils (Lambert, 1968). He proposed the use of an empirical constant (Ω) based on a standard soil to account for the variability. For example, a value of $\Omega = 0.5$ for a given soil would imply that the soil organic carbon would only be 50% as "efficient" as that in the standard soil. No data are presently available to establish whether the Ω value is a constant for a given soil regardless of the pesticide. Furthermore, selection of a "standard" soil would be somewhat ambiguous. Considering the practical utility of a "universal" adsorption partition coefficient for each pesticide which is essentially independent of the soil type, the errors introduced by above discussed factors may be relatively minor.

An exhaustive literature search was performed to compile adsorption isotherm parameters (K, K_D, N, K_{OC}) for a number of pesticides and related compounds. The list of compounds included in this search was prepared on the basis of "benchmark" pesticides (Goring et al., 1973; George Washington Univ., 1976; Sanborn et al., 1977) and cover a broad spectrum of herbicides, insecticides, and fungicides frequently used in agriculture. A complete listing of K, K_D, N, and K_{OC} values is included in the appendix of this report, while only overall means and coefficients of variation (CV) are shown in Table 4-1.

It is evident from the data presented in Table 4-1 that the CV values for K (or K_D) ranged from 13.5% to 158.5%, while the CV for K_{OC} are much lower. This supports the previous suggestions that K_{OC} may be a universal adsorption partition coefficient for each pesticide. The values of N are not as variable as the K values; the overall mean and CV for N are, respectively, 0.87 and 14.8%. Therefore, the assumption of linear isotherms required in using K_{OC} values is apparently not valid for many pesticides. The error introduced by assuming linear isotherms (N = 1), however, are within a factor of two or three as demonstrated earlier (See Fig. 4-1).

There seem to be three major reasons for the rather large variability in the K_{OC} values shown in Table 4-1. First, the relationship between K_D and %OC may be nonlinear. However, multiple regression analysis using this data base did not reveal any consistent or significant trends in this regard. Second, although the variability in K_{OC} values from a given reference were generally low (CV = 40-60%), the CV for K_{OC} values pooled from several references was generally higher. This trend suggests that experimental methods employed by various authors may not have been the same. For example, shaking method, contact time allowed between pesticide and soil, temperature, and the analytic method used to assay the pesticide will contribute to the variability noted. The third factor was whether the adsorption parameters K or K_D were derived from an entire isotherm or at a single concentration. Recall that K = K_D for linear isotherms, while for nonlinear isotherms K_D is concentration-dependent. Therefore, adsorption coefficients determined from single point measurement can yield under-estimates of the actual value of K. The results presented in this section clearly point out the need for standardization of experimental methods (or protocols) for measuring adsorption isotherm parameters.

Octanol-Water Partitioning

In spite of two decades of extensive research efforts, the adsorption isotherm parameters are available only for few of the large number of pesticides and related organic compounds currently in use. Therefore, several attempts have been made to develop methods for predicting the adsorption partition coefficients from available physical-chemical parameters of the pesticides and soils. The concept of K_{OC}, discussed earlier, is one such method. Two methods based on extra-thermodynamic linear free energy concepts are discussed in this section.

Several authors (Weber, 1966; Ward and Holly, 1966) have shown a close relationship between the chemical structure and pesticide adsorption on soils. Based upon such observations, Lambert (1969) derived a linear relationship between the "parachor" and the adsorption partition coefficient (K_{OC}). Parachor is an additive and constitutive function of molecular structure and is related to molar volume (V_m) and surface tension (r) as follows: $P = V_m r^{1/4}$.

TYPING GUIDE SHEET

Table 4-1. Summary of Adsorption Partition Coefficient Values Compiled from Published Literature for Several Pesticides and Related Organic Compounds.

Pesticide	Number of Soils	K or K_D Mean (%CV)	N Mean (%CV)	K_{oc} Mean (%CV)	ln K_{oc} Mean (%CV)
AMETRYNE	32	6.16(65.1)		388.4(57.1)	5.808(9.8)
AMIBEN	12	1.40(145.2)		189.6(149.7)	3.748(52.0)
ATRAZINE	56	3.20(89.8)	0.86(9.9)	163.0(49.1)	4.966(10.7)
BROMACIL	2			72.0(102.1)	
CARBOFURAN	5	1.05(111.8)	0.96(6.5)	29.4(30.0)	3.336(9.9)
CHLOROBROMURON	5	37.22(121.2)	0.74(8.8)	995.6(55.1)	6.804(6.9)
CHLORONEB	1			1652.9(--)	
CHLOROXURON	5	234.0(71.1)		4343.3(28.8)	8.343(3.5)
CHLORPROPHAM	36			816.3(--)	
CHLORTHIAMID	6	5.57(39.7)		98.3(27.5)	4.549(7.2)
CIODRIN	3			74.8(59.1)	
DDT	2			243118.0(65.0)	
DICAMBA	5	0.11(103.9)	1.18(13.7)	2.2(73.5)	0.611(94.3)
DICHLOBENIL	34	3.0(70.9)		224.4(77.4)	5.223(11.0)
DIMETHYL AMINE	5	14.0(77.3)	1.00(0.5)	434.9(19.8)	6.058(3.4)
DIPROPETRYNE	5	13.5(91.5)	0.86(3.9)	1180.8(74.9)	6.874(10.2)
DISULFOTON	20	32.3(91.7)	0.92(10.3)	1603.0(144.2)	7.027(9.8)
DIURON	84	8.9(150.8)	0.83(28.8)	382.6(72.4)	5.680(14.8)
FENURON	10	2.11(120.8)	0.87(13.2)	42.2(84.7)	3.536(17.2)
LINDANE	3	20.1(13.5)		1080.9(13.0)	6.980(1.9)

(Continued)

TYPING GUIDE SHEET

Table 4-1 (Continued)

Pesticide	Number of Soils	K or K_D Mean (%CV)	N Mean (%CV)	K_{oc} Mean (%CV)	ln K_{oc} Mean (%CV)
LINURON	33	21.2(100.2)	0.71(6.6)	862.8(72.3)	6.55(10.1)
MALATHION	20	34.1(67.1)		1796.9(65.9)	7.303(8.6)
METHYL PARATHION	7	12.7(67.2)	0.94(12.9)	5101.5(113.6)	7.673(20.9)
METHYL UREA	5	3.5(80.1)		58.8(15.1)	4.066(3.7)
METOBROMURON	4	6.7(62.8)	0.76(15.7)	271.5(37.1)	5.553(6.6)
MONOLINURON	10	12.3(83.6)	0.76(10.1)	284.3(55.2)	5.514(9.9)
MONURON	18	7.6(122.5)	0.83(20.6)	183.5(60.8)	5.069(10.7)
NEBURON	5	166.8(68.3)		3110.5(23.5)	8.018(3.2)
p-CHLOROANILINE	5	16.8(79.4)	0.70(2.6)	561.5(33.6)	6.286(5.3)
PARATHION	4	21.9(63.7)	1.03(2.9)	10650.3(74.6)	9.042(8.9)
PHENYL UREA	5	4.9(91.9)		76.3(12.3)	4.324(3.8)
PICLORAM	26	0.63(150.2)	0.85(13.2)	25.5(138.5)	2.692(36.4)
PROMETONE	29	7.2(147.5)	0.81(4.4)	524.3(143.6)	5.721(17.4)
PROMETRYNE	38	10.8(123.8)	0.82(5.3)	614.3(99.1)	6.100(12.9)
PROPAZINE	36	3.1(135.8)	0.95(3.6)	153.5(37.0)	4.949(9.2)
SIMAZINE	147	2.3(158.5)	0.78(5.2)	138.4(12.6)	4.625(15.5)
TELONE (cis)*	6	54.8(78.6)		798.1(44.3)	6.598(6.8)
TELONE (trans)*	6	93.2(72.0)		1379.0(45.4)	7.140(6.6)
TERBACIL	4	0.78(145.0)	0.93(6.1)	41.2(42.2)	3.646(12.3)
THIMET	4	8.8(77.7)	0.97(4.2)	3255.2(49.5)	7.984(6.7)
TRITHION	4	74.6(26.6)	0.94(7.4)	46579.7(80.2)	10.419(10.0)
2,4-D	9	0.78(128.6)	1.01(4.0)	19.6(72.4)	2.823(19.1)
2.4-D AMINE	3	2.0(112.5)	0.75(9.0)	109.1(30.2)	4.657(7.2)
2,4,5-T	4	1.6(87.3)		80.1(45.3)	4.296(11.6)

*Vapor-soild adsorption

EPA-287 (Cin.)
(4-76)

Comparison of parachor values for various compounds is therefore equivalent to comparison of their molar volumes modified to account for the differences in surface tension. Using the data of Hance for seven phenyl urea herbicides, Lambert (1967) confirmed the linear relationship between P and K_{oc}. However, Briggs (1969) found poor correlations between P and K_{oc}. It was pointed out by Hance (1969) that the concept of parachor should be used only with unionized molecules that do not form hydrogen bonds. Because of difficulties in calculating the parachor values for pesticides, this concept has not been thoroughly tested. However, important theoretical advances in molecular structure-activity relationship are now being made (Hopfinger and Klopman, 1978; Hopfinger and Battershell, 1976; Forsythe and Hopfinger, 1978).

Lambert and coworkers (1965, 1966, 1967, 1968) have suggested that the role of soil organic matter in adsorption of neutral organic molecules was similar to that of an organic solvent in liquid-liquid extraction. They further state that K_{oc} values should be related to pesticide partitioning between water and an immiscible organic solvent. Although various organic solvents could potentially be used, a considerably large data base and sound theoretical basis currently exists for 1-octanol water partition coefficients (Leo et al., 1971). More recently several authors have reported K_{oc} values for a range of pesticides and industrial organic wastes (Metcalf and Lu, 1978; Karickhoff and Brown, 1978; Briggs, 1973; Chiou et al., 1977; Kenaga, 1975; Karickhoff et al., 1979). A linear relationship between log K_{ow} and log K_{oc} values for 30 pesticides was reported by Briggs. Similarly, Karickhoff (1979) obtained the following relationships for s-triazines and dinitro-aniline herbicides

$$\log K_{oc} = 0.94 \log K_{ow} + 0.02 \qquad [4\text{-}25]$$

and for polycyclic aromatic hydrocarbons (Karickhoff and Brown, 1978),

$$\log K_{oc} = 1.0 \log K_{ow} + 0.21 \qquad [4\text{-}26]$$

K_{ow} values for several pesticides reported in the literature are summarized in Table 4-2. These K_{ow} values were paired with available K_{oc} values (see Table 4-1) and were used to obtain the following regression equation (r^2 = 0.91)

$$\log K_{oc} = 1.029 \log K_{ow} + 0.18 \qquad [4\text{-}27]$$

A graphical representation of Eqs. [4-25] and [4-27], along with the data for 13 pesticides, is presented in Fig. 4-3. An excellent agreement between Eqs. [4-25], [4-26], and [4-27] is apparent. This is especially important considering the fact that the data used to develop Eq. [4-27] was obtained from several references.

It is apparent from the above discussion that octanol-water partition coefficients may be good predictors of adsorption partition coefficients for pesticides. Furthermore, K_{ow} values have also been successfully used as predictors of bioaccumulation potentials and bioactivity indicators for a wide range of environmental contaminants (Metcalf and Lu, 1978; Chiou et al., 1977)

Table 4-2. Summary of Octanol-Water partition Coefficients (K_{ow}) for Pesticides Compiled from Literature.

Pesticide	Analytic Method	K_{ow}	Log K_{ow}
A. INSECTICIDES			
ALDICARB[1]	?	5.00000E+00	6.98970E-01
ALTOSID[1]	3H	1.76000E+02	2.24551E+00
CARBARYL[1]	14C	6.51000E+02	2.81358E+00
CARBOFURAN[1]	14C	2.07000E+02	2.31597E+00
CHLORDANE[1]	?	2.10800E+03	3.32387E+00
CHLORPYRIFOS[1]	GC	2.05900E+03	3.31366E+00
CHLORPYRIFOS[2]	?	6.60000E+04	4.81954E+00
CHLORPYRIFOS[3]	GC	1.28825E+05	5.11000E+00
CHLORPYRIFOS, METHYL[1]	?	1.97000E+03	3.29447E+00
CHLORPYRIFOS, METHYL[3]	GC	2.04170E+04	4.30999E+00
DDD[1]	?	1.15000E+05	5.06070E+00
DDE[1]	?	7.34450E+04	4.86596E+00
DDE p,p[2]	?	4.89779E+05	5.69000E+00
DDT[2]	?	3.70000E+05	5.56820E+00
DDT p,p[2]	?	1.54882E+06	6.19000E+00
DDVP[1]	GC	1.95000E+02	2.29003E+00
DIALIFOR[3]	GC	4.89780E+04	4.69000E+00
DIAZINON[1]	GC	1.05200E+03	3.02202E+00
DICHLOFENTHION[3]	GC	1.38038E+05	5.14000E+00
DICIFOL[1]	?	3.46100E+03	3.53920E+00
DIELDRIN[1]	14C	4.93000E+03	3.69285E+00
DINOSEB[1]	GC	1.98000E+02	2.29667E+00
ENDRIN[1]	?	1.61900E+03	3.20925E+00
ETHOXYCHLOR[1]	?	1.18000E+03	3.07188E+00
FENITROTHION[3]	GC	2.29900E+03	3.36154E+00
HCB[2]	?	1.66000E+06	6.22011E+00
HEPTACHLOR[1]	?	7.36600E+03	3.86723E+00
LEPTOFOS[1]	14C	4.12200E+03	3.61511E+00
LEPTOPHOS[3]	GC	2.04174E+06	6.31000E+00
LINDANE[1]	GC	6.43000E+02	2.80821E+00
MALATHION[1]	14C	2.30000E+02	2.36173E+00
MALATHION[3]	GC	7.76000E+02	2.88986E+00
METHOMYL[1]	UV	1.20000E+01	1.07918E+00
METHOXYCHLOR[1]	3H	2.05000E+03	3.31175E+00
METHOXYCHLOR[4]	GC	1.20000E+05	5.07918E+00
METHYL PARATHION[1]	14C	2.07600E+03	3.31723E+00
PARATHION[3]	GC	6.45500E+03	3.80990E+00
PERMETHRIN[1]	GC	7.53000E+02	2.87679E+00

(Continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table 4-2. (Continued)

Pesticide	Analytic Method	K_{ow}	Log K_{ow}
PHORATE[1]	?	8.23000E+02	2.91540E+00
PHOSALONE[3]	GC	1.99530E+04	4.30001E+00
PHOSMET[3]	GC	6.76000E+02	2.82995E+00
PROPOXUR[1]	?	2.80000E+01	1.44716E+00
RONNEL[3]	GC	7.58580E+04	4.88000E+00
TERBUFOS[1]	?	1.67000E+02	2.22272E+00
TOXAPHENE[1]	?	1.69500E+03	3.22917E+00
B. HERBICIDES			
ALACHLOR[1]	GC	4.34000E+02	2.63749E+00
ATRAZINE	14C	2.12000E+02	2.32634E+00
ATRAZINE[1]	14C	2.26000E+02	2.35411E+00
BIFENOX[1]	14C	1.74000E+02	2.24055E+00
BROMACIL[1]	?	1.04000E+02	2.01703E+00
CHLORAMBEN[1]	UV	1.30000E+01	1.11394E+00
CHLOROPROPHAM[1]	GC	1.16000E+03	3.06446E+00
DALAPON[2]	?	5.70000E+00	7.55875E-01
DALAPON, NA SALT[2]	?	1.00000E+00	0.00000E+00
DICAMBA[1]	14C	3.00000E+00	4.77121E-01
DICHLOBENIL[1]	UV	7.87000E+02	2.89597E+00
DIURON[1]	UV	6.50000E+02	2.81291E+00
MONURON[1]	UV	1.33000E+02	2.12385E+00
MSMA[1]	AA	8.00000E-04	-3.09691E+00
NITROFEN[1]	?	1.24500E+03	3.09517E+00
PARAQUAT .2HCL[1]	14C	1.00000E+00	0.00000E+00
PICLORAM[2]	?	2.00000E+00	3.01030E-01
PROPACHLOR[1]	?	4.10000E+01	1.61278E+00
PROPANIL[1]	?	1.06000E+02	2.02531E+00
SIMAZINE[1]	14C	8.80000E+01	1.94448E+00
TERBACIL	14C	7.80000E+01	1.89209E+00
TRIFLURALIN[1]	14C	1.15000E+03	3.06070E+00
2,4-D	14C	4.16000E+02	2.61909E+00
2,4-D[1]	14C	4.43000E+02	2.64640E+00
2,4-D[5]	?	6.46000E+02	2.81023E+00
2,4,5-T[2]	?	7.00000E+00	8.45098E-01
2,4,5-T, BUTYL ESTER[2]	?	6.40000E+04	4.80618E+00
2,4,5-T OCTYL ESTER[2]	14C	9.09000E+02	2.95856E+00

(Continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE
6 1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table 4-2. (Continued)

Pesticide	Analytic Method	K_{ow}	Log K_{ow}
C. FUNGICIDES			
BENOMYL[1]	GC	2.64000E+02	2.42160E+00
CAPTAN[1]	UV	3.30000E+01	1.51851E+00
PCP[1]	14C	1.42900E+04	4.15503E+00

References

1. Metcalf, R.L., and P.Y. Lu. 1978. Partition coefficients as measures of bioaccumulation potential for organic compounds. EPA report (in press).

2. Kenaga, E.E. 1975. Partitioning and uptake of pesticides by biological systems. In Environmental Dynamics of Pesticides (eds: R. Haque and V.H. Freed), Plenum Press, N.Y. p. 217-275.

3. Chiou, C.T., V.H. Freed, D.W. Schmedding, and R.L. Kohnert. 1977. Partition coefficients and bioaccumulation of selected organic chemicals. Environ. Sci. Technol. 11:475-478.

4. Karickhoff, S.W., and D.S. Brown. 1978. Paraquat sorption as a function of particle size in natural sediments. J. Environ. Qual. 7:246-252.

5. Leo, A., C. Hanch, and D. Elkins. 1971. Partition coefficients and their uses. Chem. Rev. 71:525-616.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

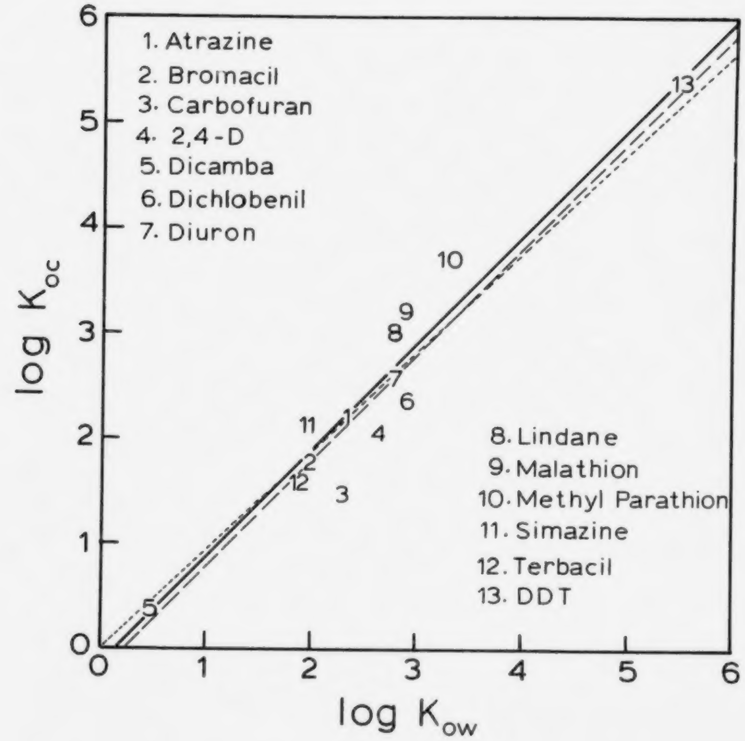


Figure 4-3. Relationship between K_{oc} and K_{ow} values for pesticides reported in the literature. The solid line is a plot of Eq. 4-27. The dashed lines are plots of Eqs. 4-25 and 4-26 and represent best-fit lines for data reported for s-triazines, dinitroanalines, and polycyclic aromatic hydrocarbons.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA
OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Measurement of K_{OW} values should yield a valuable data base for future use.

Effects of Soil-Particle Size

The adsorption partition coefficients reported thus far in this manuscript are for whole soils. The distribution of the adsorbed pesticide between the various size fractions of the soil was not given any consideration. Because of the larger specific surface area and higher organic carbon content, the finer fractions are expected to adsorb larger quantities of pesticides than the coarser fractions such as sand. A limited amount of work in this area has been reported by Karickhoff and Brown (1978) and Karickhoff et al., (1979). These authors studied the adsorption of two pesticides and several polycyclic aromatic hydrocarbons on several sediments and reported that the total amount of pesticide adsorbed by the whole soil (denoted S, μ/g soil) can be written as,

$$S = \sum_{i=1}^{n} f^i S^i \qquad [4\text{-}28]$$

where, S^i is the amount adsorbed (μg/g size-fraction) and f^i is the fraction of the total soil mass represented by ith size-fraction. Assuming a linear adsorption isotherm, Eq. [4-28] can be restated as:

$$S = \sum_{i=1}^{n} f^i S^i = \sum_{i=1}^{n} f^i K_D^i C = \overline{K}_D C \qquad [4\text{-}29]$$

where, $\overline{K}_D$ and K_D^i are the average partition coefficients for the whole soil and the ith size fraction. It is apparent from Eq. [4-29] that,

$$\overline{K}_D = \sum_{i=1}^{n} K_D^i f^i. \qquad [4\text{-}30]$$

It follows from Eqs. [4-28] and [4-30] that,

$$S^i = K_D^i (S/\overline{K}_D) \qquad [4\text{-}31]$$

Therefore, the amount of pesticide adsorbed on any particle-size fraction can be estimated given the mass fraction and partition coefficient for each size fraction and the adsorbed concentration for the whole soil (sediment).

Karickhoff and Brown (1978) and Karickhoff et al. (1979) have measured the adsorption of two pesticides and several polycyclic aromatics as a function particle-size on several natural sediments. They reported that adsorbed concentrations varied over orders of magnitude among individual size fractions with a pronounced preference towards the fine silt and clay fractions. Differences in amount adsorbed were directly related to the organic carbon content variations associated with each particle-size fraction. Based on these findings, Eq. [4-30] can be restated as follows

$$\overline{K}_D = \sum_{i=1}^{n} K_{oc}^i f^i (OC)^i \qquad [4\text{-}32]$$

where, K_{OC}^{i} are the adsorption partition coefficients "normalized" with respect to the organic carbon content, OC^{i}, of the i^{th} size.

The K_{OW} values for sand-size fraction were less than half of those for finer size fractions (silt and clay); the sand fraction thus dilutes the effects of the fines. A portion of their data for adsorption of pyrene and methoxychlor on one sediment are shown in Table 4-3. Based on similar data for other natural sediments, Karickhoff et al. (1979) recommended measurement of K_{OC}^{i} values for sediment fines (< 50 μm size) only. They also found excellent agreement between K_{OC} values and K_{OW} values (See Eq. 4-25). Thus, the problem of predicting the distribution of the amount adsorbed onto various size-fractions reduces to that of determining the following parameters: (i) mass fraction and organic carbon content of the fines, and (ii) determining the K_{OW} value for the compound of interest. Further testing of this approach is urgently needed, especially for a variety of soil-pesticide combinations.

PESTICIDE LOSSES IN RUNOFF

For each runoff event, a certain amount of the applied pesticide is lost both in the runoff water as well as with the sediment in the runoff. The relative amounts of pesticide lost in each of these two phases may be estimated as follows (Mulkey and Falco, 1977):

$$F_w = [1 + \rho_s \bar{K}_D]^{-1} \qquad [4\text{-}35]$$

$$F_s = [1 + \frac{1}{\rho_s \bar{K}_D}]^{-1} \qquad [4\text{-}36]$$

Where, ρ_s is the sediment concentration in the runoff (g/ml), $\bar{K}_D$ is the average adsorption partition coefficient (ml/g), F_w is the fraction pesticide lost in the water phase, and F_s is the fraction of pesticide loss associated with the sediment phase. In deriving Eqs. [4-35] and [4-36] it was assumed that the adsorption-desorption isotherms were linear and singular and that sorption equilibrium is achieved instantaneously. Limitations of these assumptions were discussed in earlier sections.

Using Eq. [4-35] the values of F_w were calculated for a broad range of ρ_s and $\bar{K}_D$ values. These are listed in Table 4-4. It is evident that most of the pesticide (> 90%) is lost in the water phase of the runoff, except for highly adsorbed pesticides ($\bar{K}_D > 100$) or for high sediment loads ($\rho_s > 1000$). Data from recent field studies (Smith et al., 1978; Leonard et al., 1979) confirm these conclusions. It should be recognized that the pesticide concentrations in the sediment-phase are generally much larger than those in the water-phase. However, because of much larger volume of water in the runoff compared to the sediment mass, the total pesticide loss in the water-phase is greater.

Wauchope (1978) presents an excellent review of the literature on pesticide losses measured in runoff from agricultural watersheds. The data he

Table 4-3. Adsorption Partition Coefficients (K_D^i and K_{oc}^i) for Various Particle-Size Fractions of Hickory Hill Sediment.
(Adapted from Karickhoff and Brown, 1978)

Particle-Size Fraction	% OC	Pyrene K_D^i	Pyrene $K_{oc}^i \times 10^{-5}$	Methoxychlor K_D^i	Methoxychlor $K_{oc}^i \times 10^{-5}$
SAND	0.13	42	0.32	53	0.41
COARSE SILT	3.27	3000	0.92	2600	0.80
MEDIUM SILT	1.98	2500	1.30	1800	0.91
FINE SILT	1.34	1500	1.10	1400	1.00
CLAY	1.20	1400	1.20	1100	0.92

Table 4-4. Influence of $\bar{K}_D$ and ρ_s on the Pesticide Lost in the Water-Phase of the Runoff. Values Shown are % of the Total Loss.

Adsorption Partition Coeff., $\bar{K}_D$ (ml/g)	Sediment Concentration, ρ_s (mg/l)				
	10^2	10^3	10^4	10^5	10^6
10^{-1}	99.99	99.99	99.90	99.01	90.01
10^0	99.99	99.90	99.01	90.91	50.00
10^1	99.90	99.01	90.91	50.00	9.09
10^2	99.01	90.91	50.00	9.09	0.99
10^3	90.91	50.00	9.09	0.99	0.11

compiled demonstrated that total pesticide losses in the runoff were in general less than 0.5% of the amount applied; paraquat herbicide and organochlorine insecticides that are highly sorbed to the soil were the exceptions. Single event losses as high as 10% were recorded when the runoff event occurred on the site shortly after pesticide application. However, the probability of such events, termed "catastrophic" events, appears to be low under most field conditions. The total pesticide loss in each runoff event generally decreased exponentially with time and was strongly correlated with the total amount of pesticide remaining in the runoff active zone (0-1 cm depth) of the soil surface (Leonard et al., 1979; Smith et al., 1978). Therefore, the pesticide losses in runoff are dependent upon the "available" amount of pesticide in the surface soil, which in turn is determined by the persistance, retention, and mobility of the pesticides.

SUMMARY

A considerably large data base exists for estimating the partition coefficients for pesticide retention on soils. Errors associated various simplifying assumptions (e.g., linear and singular isotherms; instantaneous equilibrium) appear to be within a factor of 2 or 3 and may be tolerable for most NPS pollution applications. For a given pesticide, adsorption partition coefficients based on soil organic carbon were fairly constant regardless of soil type. Furthermore, octanol water partition coefficients are good predictors of adsorption partition coefficients. More research in this area would be helpful.

Seasonal pesticide losses by runoff from agricultural fields, in general, are less than 0.5% of the amount applied. Although pesticide concentrations in the sediment phase are larger that those in the water phase, pesticide carried in the water phase accounts for > 90% of the total loss for a given runoff event. Highly sorbed pesticides (e.g., paraquat and diquat, chlorinated hydrocarbon insecticides) are the exceptions to this rule.

REFERENCES FOR SECTION 4

Adams, R. T., and F. M. Kurisu. 1976. Simulation of pesticide movement on small agricultural watersheds. Environ. Systems Lab., Calif. Report prepared for USEPA, Athens, Ga. EPA 600/3-76-066. 324 pp.

Adamson, A. W. 1967. Physical chemistry of surfaces. Interscience, N.Y.

Bailey, G. W., and J. L. White. 1964. Pesticide-Soil Colloid Interactions. Unpublished Progress Report, Grant EF-00055, Purdue Univ. 63 pp.

Bowman, M. C., M. S. Schecter, and R. L. Carter. 1965. Behavior of chlorinated insecticides in a broad spectrum of soil types. J. Agri. Food Chem. 13:360.

Briggs, G. G. 1969. Molecular structure of herbicides and their sorption by soils. Nature 223:1288.

Briggs, G. G. 1973. A simple relationship between soil sorption of organic chemicals and their octanol/water partition coefficients. Proc. 7th British Insecticides and Fungicides Conf. 11:475-478.

Briggs, G. G., and J. E. Dawson. 1970. Hydrolysis of 2,6-dichlorobenzonitrile in soils. J. Agri. Food Chem. 18:97-99.

Bruce, R. R., L. A. Harper, R. A. Leonard, W. M. Snyder, and A. W. Thomas. 1975. A model for runoff of pesticides from small upland watersheds. Journ. Environ. Qual. 4:541-548.

Burchill, S., M. H. Cardew, M. H. B. Hayes, and R. J. Smedley. 1973. Continuous flow methods for studying adsorption of herbicides by soil dispersions and soil columns. Proc. European Weed Res. Coun. Symp., Herbicides-Soil pp. 70-79.

Burnside, O. C., and T. L. Lavy. 1966. Dissipation of Dicamba. Weeds 14:211-214.

Cheng, H. H. 1977. Personal communication. Unpublished data.

Cheung, M. W. 1973. Equilibrium and kinetic processes of the interactions of 4-amino-3,5,6-trichloropicolinic acid (picloram) and O,O-diethyl-O-p-nitrophenyl phosphorothioate (parathion) with soils. Unpublished Ph.D. Thesis, Univ. of Calif., Davis.

Chiou, C. T., V. H. Freed, D. W. Schmedding, and R. L. Kohnert. 1977. Partition coefficients and bioaccumulation of sellected organic chemicals. Environ. Sci. Technol. 11:475-478.

Colbert, F. O., V. V. Volk, and A. P. Appleby. 1975. Sorption of atrazine, terbutryn, and GS-14254 on natural and lime-ammended soils. Weed Sci. 23:390-394.

Crawford, N. H., and A. S. Donigian, Jr. 1973. Pesticide transport and runoff model for agricultural lands. EPA-660/2-74-013. 212 pp.

Dao, T. H., and T. L. Lavy. 1978. Atrazine adsorption on soils as influenced by temperature, moisture content, and electrolyte concentration. Weed Sci. 26:303-308.

Davidson, J. M., L. T. Ou, and P. S. C. Rao. 1978. Adsorption, movement, and biological degradation of high concentrations of selected pesticides in soils. Proc. 4th Annual Res. Symp. "Land Disposal of Hazardous Wastes." EPA-600/9-78-016. pp. 233-244.

Day, B. E., L. S. Jordan, and V. L. Jolliffe. 1968. The influence of soil characteristics on the adsorption and phyto-toxicity of simazine. Weed Sci. 16:209-213.

Donigian, Jr., A. S., and N. H. Crawford. 1976. Modeling pesticides and nutrients on agricultural lands. EPA-600/2-76-043. 318 pp.

EPA-287 (Cin.)
(4-78)

Environmental Protection Agency. 1975. Guidelines for Registering Pesticides in United States. Federal Register. 40(123):26802-26928.

Farmer, W. J., and Y. Aochi. 1974. Picloram sorption by soils. Soil Sci. Soc. Amer. Proc. 38:418-423.

Fava, A., and H. Eyring. 1956. Equilibrim and kinetics of detergent adsorption - A generalized equilibrim theory. J. Phys. Chem. 60:890.

Forsythe, K. H., and A. J. Hopfinger. 1978. A quantitative model of biomolecular solvation. (Manuscript in review).

Frere, M. H. 1978. Models for predicting water pollution from agricultural watersheds. In Conf. on Modeling and Simulation of Land, Air, and Water Resource Systems. Int. Fed. Inf. Processes, Ghent, Belgium. pp. 501-509.

Frere, M. H., C. A. Onstad, and H. N. Holtan. 1975. ACTMO, an agricultural chemical transport model. ARS-H-3, USDA, Washington, D.C. 54 p.

Furmidge, C. G. L., and J. M. Osgerby. 1967. Persistance of herbicides in soil. J. Sci. Food Agric. 18:269-273.

Gaynor, J. D., and V. V. Volk. 1976. Surfactant effects on picloram adsorption by soils. Weed Sci. 24:549-553.

Geissbuhler, H., C. Haselback, and H. Aebi. 1963. The fate of N'-(4-chlorophenoxy)-phenyl-N,N-dimethylurea (C-1983) in soils and plants. Weed Res. 3:140-153.

George Washington Univ. 1976. A literature survey of benchmark pesticides. The George Washington Univ. Medical Center., March 1976. 252 pp.

Goring, C. A. I., J. W. Hamaker, and D. A. Laskowski. 1973. A proposed approach to PR-70-15 guidelines for studies to determine the impact of pesticides in the environment. Unpublished paper, presented at the Pesticide Division meetings of the Am. Chem. Soc., Dallas, Texas.

Graham-Bryce, I. J. 1967. Adsorption of disulfoton by soil. J. Sci. Food Agric. 18:72-77.

Green, R. E., and J. C. Corey. 1971. Pesticide adsorption measurement by flow equilibration and subsequent displacement. Soil Sci. Soc. Amer. Proc. 35:561-565.

Green, R. E., and S. R. Obien. 1969. Herbicide equilibrium in relation to soil water content. Weed Sci. 17:514-519.

Green, R. E., J. M. Davidson, and J. W. Biggar. 1976. An assessment of methods for determining adsorption-desorption of organic chemicals. Proc. Intern. Congress on Agrochemicals in Soils, ISSS, Israel. (In press).

Grice, R. E., and M. H. B. Hayes. 1972. A continuous flow method for studying adsorption and desorption of pesticides in soils and soil colloidel systems. Proc. 11th. British Weed Control Conf. 2:784-791.

Grice, R. E., M. H. B. Hayes, P. R. Lundie, and M. H. Cardew. 1973. Continuous flow method for studying adsorption of organic chemicals by a humic acid preparation. Chem. & Ind. (London) pp. 233-234.

Grover, R. 1971. Adsorption of picloram by soil colloids and various other adsorbents. Weed Sci. 19:417-418.

Grover, R. 1974. Adsorption and desorption of trifluralin, triallete, and diallete by various adsorbents. Weed Sci. 22:405-408.

Grover, R. 1975. Adsorption and desorption of urea herbicides in soils. Can. J. Soil Sci. 55:127-135.

Grover, R. 1977. Mobility of dicamba, picloram, and 2,4-D in soil columns. Weed Sci. 25:159-162.

Grover, R., and R. J. Hance. 1969. Adsorption of some herbicides by soil and roots. Can. J. Plant Sci. 49:378-380.

Grover, R., and A. E. Smith. 1974. Adsorption studies with the acid and dimethylamine forms of 2,4-D and dicamba. Can. J. Soil Sci. 54:179-186.

Hamaker, J. W., and J. M. Thompson. 1972. Adsorption. In (eds. C.A.I. Goring and J.W. Hamaker) Organic Chemicals in the Environment, Mercel Dekker Inc., N.Y. pp 51-139.

Hamaker, J. W., C. A. I. Goring, and C. R. Youngson. 1966. Sorption and leaching of 4-amino-3,5,6-trichloropicolinic acid in soils. Organic Pesticides in the Environment, Adv. in Chem. 60:23-37.

Hance, R. J. 1965. The adsorption of urea and some of its derivatives by a variety of soils. Weed Res. 5:98-107.

Hance, R. J. 1967. The speed of attainments of sorption equilibria in some systems involving herbicides. Weed Res. 7:29-36.

Hance, R. J. 1969. An empirical relationship between chemical structure and the sorption of some herbicides by soils. Jour. Agric. Food Chem. 17:667-668.

Hance, R. J. 1976. Adsorption of glyphosate by soils. Pest. Sci. 7:363-366.

Haque, R., F. T. Lindstrom, V. H. Freed, and R. Sexton. 1968. Kinetic study of the sorption of 2,4-D on some clays. Environ. Sci. Tech. 2:207-211.

Harris, C. I. 1966. Adsorption, movement, and phytotoxicity of monuron and s-triazine herbicides in soils. Weeds 14:6-10.

Harris, C. I., and T. J. Sheets. 1965. Influence of soil properties on adsorption and phytotoxicity of CIPC, diuron, and simazine. Weeds 13:215-219.

Hayes, M. H. B., M. Stacey, and J. M. Thompson. 1968. Adsorption of s-triazines by soil organic matter preparations. In Isotopes and Radiation in Soil Organic Matter Studies, IAEC, Vienna. pp. 75-90.

Helling, C. S. 1971. Pesticide mobility in soils: III. Influence of soil properties. Soil Sci. Soc. Amer. Proc. 41:743.

Hilton, H. W., and Q. H. Yuen. 1963. Adsorption of several pre-emergence herbicides by Hawaiian sugarcane soils. J. Agric. Food Chem. 11:230-234.

Hopfinger, A. J., and R. D. Battershell. 1976. Application of SCAP to drug design. 1. Prediction of octanol-water partition coefficients using solvent-dependent conformational analyses. Jour. Medicinal Che. 19:569-573.

Hopfinger, A. J., and G. Klopman. 1978. A QSAR study of nitrosamine carcinogenicity using aqueous, 1-octanol solution free energies and the associated partition coefficients as correlation features. Chemical-Biological Interactions, Vol. 20.

Hornsby, A. G., and J. M. Davidson, 1973. Solution and adsorbed fluomethuron concentration distribution in a water-saturated soil: Experimental and predicted evaluation. Soil Sci. Soc. Amer. Proc. 37:823-828.

Jamet, P., and M. A. Piedallu. 1975. Mouvement du carbofuran dans different types de sols. Phytiatrie-Phytopharmacie 24:279-296.

Karickhoff, S. W., and D. S. Brown. 1978. Paraquat sorption as a function of particle size in natural sediments. J. Environ. Qual. 7:246-252.

Karickhoff, S. W., D. S. Brown, and T. A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Manuscript in publication. (Personal communication).

Kay, B. D., and D. E. Elrick. 1967. Adsorption and movement of Lindane in soils. Soil Sci. 104:314-322.

Kenaga, E. E. 1975. Partitioning and uptake of pesticides by biological systems. In Environmental Dynamics of Pesticides (eds. R. Haque and V.H. Freed), Plenum Press, N.Y. pp. 217-275.

King, P. H., and P. L. McCarty. 1968. A chromatographic model for predicting pesticide migration in soils. Soil Sci. 106:248-261.

Knight, B. A. G., J. Coutts, and T. E. Tomlinson. 1970. Sorption of ionized pesticides by soil. In Sorption and Transport Processes in Soils. Soc. Chem. Ind. (London). pp. 54-62.

Konrad, J. G., and G. Chesters. 1969. Degradation in soils of ciodrin, an organophosphate insecticide. J. Agri. Food Chem. 17:226-230.

Koren, E., C. L. Foy, and F. M. Ashton. 1969. Adsorption, volatility, and migration of thiocarbamate herbicides in soil. Weed Sci. 17:148-153.

Lambert, S. M. 1966. The influence of soil-moisture on herbicidal response. Weeds 14:273-275.

Lambert, S. M. 1967. Functional relationship between sorption in soil and chemical structure. J. Agric. Food Chem. 15:572-576.

Lambert, S. M. 1968. Omega (Ω) a useful index of soil sorption aquilibria. J. Agric. Food Chem. 16:340-343.

Lambert, S. M., P. E. Porter, and H. Schieferstein. 1965. Movement and sorption of chemicals applied to soils. Weeds 13:185-190.

Langmuir, I. 1918. J. Amer. Chem. Soc. 40:1361. As cited by Lindstrom et al. See ref. 21.

Lapidus, L., and N. R. Amundson. 1952. Mathematics of adsorption in beds. VI. The effect of longitudinal diffusion in ion exchange and chromatographic columns. J. Phys. Chem. 56:984-988.

Leenheer, J. A., and J. L. Ahlrich. 1971. A kinetic and equilibrium study of the adsorption of carbaryl and parathion upon soil organic matter surfaces. Soil Sci. Soc. Amer. Proc. 35:700-704.

Leo, A., C. Hanch, and D. Elkins. 1971. Partition coefficients and their uses. Chem. Rev. 71:525-616.

Leonard, R. A., G. W. Langdale, and W. G. Flemming. 1979. Herbicide runoff from upland piedmont watersheds--Data and implications for modeling pesticide transport. Jour. Environ. Qual. 8:223-229.

Liestra, M. 1970. Distribution of 1,3-dichloropropene over the phases of soil. J. Agri. Food Chem. 18:1124-1126.

Lindstrom, F. T., R. Haque, and W. R. Coshow. 1970. Adsorption from solution. III. A new model for the kinetics of adsorption-desorption processes. J. Phys. Chem. 74:495-502.

Liu, L. C., H. Cibes-Viade, and F. K. S. Koo. 1970. Adsorption of ametoyne and diuron by soils. Weed Sci. 18:470-474.

Macnamara, G., and S. J. Toth. 1970. Adsorption of Linuron and malathion by soils and clay minerals. Soil Sci. 109:234-240.

Majka, J. T., and T. L. Lavy. 1977. Adsorption, mobility, and degradation of cyamazine and diuron by soils. Weed Sci. 25:401-406.

McGlamery, M. D., and F. W. Slife. 1966. The adsorption and desorption of atrazine as affected by pH, temperature, and concentration. Weeds 14:237-239.

Metcalf, R. L., and P. Y. Lu. 1978. Partition coefficients as measures of bioaccumulation potential for organic compounds. EPA report (in press).

Mukhtar, M. 1976. Desorption of adsorbed ametryn and diuron from soils and soil components in relation to rates, mechanisms, and energy of adsorption reactions. Unpublished Ph.D. Dissertation, Univ. of Hawaii.

Mulkey, L. A., and J. W. Falco. 1977. Sedimentation and erosion control implications for water quality management.

Murray, D. S., P. W. Santelman, and J. M. Davidson. 1975. Comparative adsorption, desorption, and mobility of dipropetryn and prometryn in soil. J. Agric. Food Chem. 23:578-582.

Obien, S. R., and R. E. Green. 1969. Degradation of atrazine in four Hawaiian soils. Weed Sci. 17:509-514.

Oddson, J. K., J. Ketey, and L. V. Weeks. 1970. Predicted distribution of organic chemicals in solution and adsorbed as a function of position and time for various chemical and soil properties. Soil Sci. Soc. Amer. Proc. 34:412-417.

O'Connor, G. A., and J. V. Anderson. 1974. Soil factors affecting the adsorption of 2,4,5-T. Soil Sci. Soc. Amer. Proc. 38:433-436.

Peck, D. E. 1977. The adsorption-desorption of diuron by fresh water sediments. Unpublished M.S. Thesis, Univ. of Calif. Riverside.

Rao, P. S. C. 1974. Pore-geometry effects on solute dispersion in aggregated soils and evaluation of a predictive model. Ph.D. Dissertation, Univ. of Hawaii.

Rao, P. S. C., and J. M. Davidson. 1979. Adsorption and movement of selected pesticides at high concentrations in soils. Water Res. 13:375-380.

Rao, P. S. C., and J. M. Davidson. 1980. Unpublished Manuscript.

Rao, P. S. C., J. M. Davidson, and D. P. Kilcrease. 1978. Examination of nonsingularity of adsorption-desorption isotherms for soil-pesticide systems. Agron. Abstr. p. 34. (Manuscript submitted to Soil Sci. Soc. Amer. Jour.)

Rao, P. S. C., J. M. Davidson, R. E. Jessup, and H. M. Selim. 1979. Evaluation of conceptual models for describing non-equilibrium adsorption-desorption of pesticides during steady-flow in soils. Soil. Sci. Soc. Amer. Jour. 43:22-28.

Rhodes, R. C., I. J. Belasco, and H. L. Pease. 1970. Determination of mobility and adsorption of agricultural chemicals in soils. J. Agri. Food Chem. 18:524-528.

Roberts, H. A., and B. J. Wilson. 1965. Adsorption of chlorpropham by different soils. Weed Res. 5:348-350.

Sanborn, J. R., B. M. Francis, and R. L. Metcalf. 1977. The degradation of selected pesticides in soil: A review of published literature. EPA-600/9-77-022.

Savage, K. E., and R. D. Wauchope. 1974. Fluometuron adsorption-desorption equilibria in soils. Weed Sci. 21:106-110.

Schliebe, K. A., O. C. Burnside, and T. L. Lavy. 1965. Dissipation of Amiben. Weeds 13:321-325.

Selim, H. M., J. M. Davidson, and R. S. Mansell. 1976. Evaluation of a two-site adsorption-desorption model for describing solute transport in soils. Proc. Summer Computer Simulation Conf., Washington, D.C. pp. 444-448.

Sheets, T. J., A. S. Crafts, and H. R. Drever. 1962. Influence of soil properties on the phytotoxicity of s-triazines. J. Agric. Food Chem. 10:458-462.

Sherbourne, H. R., and V. H. Freed. 1954. Adsorpton of 3 (p- chlorophenyl)-1,1-dimethyl urea as a function of soil constituents. J. Agric. Food Chem. 2:937.

Shin, Y. O., J. J. Chodan, and A. R. Wolcott. 1970. Adsorption of DDT by soils, soil fractions, and biological materials. J. Agri. Food Chem. 18:1129-1133.

Smith, C. N., R. A. Leonard, G. W. Langdale, and G. W. Bailey. 1978. Transport of agricultural chemicals from upland piedmont watersheds. EPA-600/3-78-056.

Snoeyink, V. L., W. J. Weber, Jr., and H. B. Mark, Jr. 1969. Sorption of phenol and nitrophenol by active carbon. Environ. Sci. Technol. 3:918-926.

Swanson, R. A., and G. R. Dutt. 1973. Chemical and physical processes that affect atrazine movement and distribution in soil systems. Soil Sci. Soc. Amer. Proc. 37:872-876.

Talbert, R. E., O. H. Fletchall. 1965. The adsorption of some s-triazines in soils. Weeds 13:46-52.

Talbert, R. E., R. L. Runyan, and H. R. Baker. 1969. Behavior of amiben and dinoben derivatives in Arkansas soils. Weed Sci. 17:10-15.

Thomas, J. M., and W. J. Thomas. 1967. Introduction to the Principles of Heterogeneous Catalysis. Academic Press, N.Y.

van Bladel, R., and A. Moreale. 1976. Influence of soil properties on adsorption of pesticide-derived aniline and p-chloroaniline. J. Soil Sci. 27:48-57.

van Bladel, R., and A. Moreale. 1977. Adsorption of herbicide-derived p-chloroaniline residues in soils: A predictive equation. J. Soil Sci. 28:93-102.

van Genuchten, M. Th., J. M. Davidson, and P. J. Wierenge. 1974. An evaluation of kinetic and equilibrim equations for the prediction of pesticide movement through porous media. Soil Sci. Soc. Amer. Proc. 38:29-35.

Wahid, P. A., and N. Sethunathan. 1978. A sample method to study pesticide sorption in soils at short time intervals. Soil Sci. 126:56-58.

Walker, A., and D. V. Crawford. 1968. The role of soil organic matter in adsorption of the triazine herbicides by soils. Isotopes and Radiation in Soil-Organic Matter Studies., IAEC, Vienna pp. 91-108.

Walker, A., and D. V. Crawford. 1970. Diffusion coefficients for two triazine herbicides in six soils. Weed Res. 10:126-132.

Ward, T. M., and K. Holly. 1966. The sorption of s-triazines by model nucleophiles as related to their partitioning between water and cyclohexane. Jour. Colloid. Interface Sci. 22:221-230.

Wauchope, R. D. 1978. The pesticide content of surface water draining from agricultural fields: A Review. Jour. Environ. Qual. 7:459-472.

Weber, J. B. 1966. Molecular structure and pH effects on the adsorption of 13 s-triazine compounds on montmorillonite clay. The Amer. Minerologist 51:1657-1670.

Weber, Jr., W. J., and J. P. Gould. 1966. Sorption of organic pesticides from aqueous solution. Adv. Chem. Series 60:280-305.

Wildung, R. E., G. Chesters, and D. E. Armstrong. 1968. Chloramben (amiben) degradation in soil. Weed Res. 8:213-225.

Williams, J. D. H. 1968. Adsorption and desorption of simazine by some Rothamsted soils. Weed Res. 8:327-335.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

Yaron, B., A. R. Swoboda, and G. W. Thomas. 1967. Aldrin adsorption by soils and clays. J. Agri. Food Chem. 15:671-675.

6-1/2"
9-1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

SECTION 5

PESTICIDE TRANSFORMATIONS IN SOILS

L.T. Ou, J.M. Davidson, P.S.C. Rao, and W.B. Wheeler

Three important aspects of pesticide degradation are: mechanism, pathway, and rate of degradation. Photochemical, chemical, and microbiological transformations are generally considered to be the principal pesticide degradation mechanisms in soils. Among these, photodecomposition is of little practical significance for pesticides located below the soil surface, while microbiological transformations are of major importance because they result in an extensive breakdown (H_2O, CO_2, and simple inorganic ions) of the pesticide molecule.

AEROBIC AND ANAEROBIC DEGRADATION

Soil and environmental factors that determine pesticide degradation rates are: soil type, soil-water content, pH, temperature, clay and organic matter content. The most profound and yet frequently unpredictable factor influencing pesticide degradation rate is soil microbial activity. The nature and composition of the microbial populations as well as the soil environmental variables that control their activity are important factors in pesticide degradation. Temperature and soil-water content are two environmental factors that have been intensively studied in this regard. In general, these studies have shown that increased microbial activity at higher temperatures have enhanced pesticide degradation. For example, picloram herbicide degradation was low at 5°C, while more extensive degradation occurred at 30°C or 50°C depending on soil type (Guenzi and Beard, 1976). The half-lives of pesticides have also been shown to increase with decreasing soil-water content (Guenzi and Beard, 1976; Walker, 1976a,b). Higher adsorption and lower microbial activities may be responsible for the reduced degradation at low soil-water contents. At high soil-water contents (approaching saturation), pesticide degradation rates may be determined by the relative rate of decomposition under aerobic versus anaerobic conditions.

The soil surface is generally aerobic. However, as the soil-water content approaches saturation and/or the surface becomes submerged under water, the availability of atmospheric oxygen is reduced. Oxygen trapped in the soil is quickly depleted by the activity of the aerobic soil microorganisms for these cases. Thus, within a short period of time, the soil environment becomes anaerobic. Except for a thin layer (few mm thick) at the water-soil interface, the soil changes from an oxidized state to that of a reduced state (Sethunathan, 1973). Anaerobic environments are also encountered

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

when soil is carried by runoff water and results in sediment at the bottom of ponds, streams, rivers or other bodies of water. The rates and pathways of pesticide degradation under unaerobic conditions (flooded or submerged) may differ significantly from those for aerobic conditions.

Some compounds when present in a highly oxidized state tend to resist microbial degradation, but are susceptible to reductive decomposition under anaerobic conditions (Goring et al., 1975). For example, chlorinated hydrocarbon and organophosphorus insecticides degrade slowly under aerobic conditions but degrade more rapidly under an unaerobic environment (MacRae et al., 1967; Raghu and MacRae, 1966; Castro and Yoshida, 1971; Guenzi and Beard, 1967, 1968; Sethunathan and MacRae, 1969; Sethunathan, 1973). Also, the trifluralin herbicide has been reported to degrade more rapidly in anaerobic rather than aerobic soils (Parr and Smith, 1973). Pesticide mineralization, as indicated by CO_2 production, may be low for anaerobic conditions, but substantial quantites of intermediate metabolites frequently accumulate in anaerobic soils. Pesticide metabolites, equally or more toxic than parent compound (DDD and DDE from DDT), produced in a reduced environment on the other hand, are more susceptible to decomposition under oxidative than under reductive conditions.

QUANTITATIVE ASPECTS OF PESTICIDE TRANSFORMATIONS

Numerous reviews are presently available that deal with transformations, metabolic pathways, and persistence, and to some extent half-lives of pesticides and related toxic organic chemicals in soils (Kearny and Helling, 1969; Helling et al., 1971; Edwards, 1972; Crosby, 1973; Sethunathan, 1973; Mastumura, 1974; Howard et al., 1975; Kaufman, 1976; Sanborn et al., 1976; Laveglia and Dahn, 1977). However, none of these reviews systematically discuss pesticide degradation kinetics or attempt to relate soil and environmental properties with rates of pesticide degradation in soils. Hamaker (1966, 1972) has presented an excellent discussion of the quantitative aspects of pesticide degradation in soil. Two basic types of rate models considered were:

$$\frac{dC}{dt} = - kC^n \qquad [5\text{-}1]$$

$$\frac{dC}{dt} = - V_{max}\left[\frac{C}{\alpha+C}\right] \qquad [5\text{-}2]$$

where, C is concentration (mg/g), t is time (days), k is kinetic rate coefficient ($days^{-1}$), n is order of the reaction, V_{max} is maximum rate approached with increasing concentrations, and α is a constant. It should be noted that when n = 1, Eq. [5-1] reduces to the case of first-order kinetics, while Eq. [5-2] reduces to the case of zero-order kinetics when $C \gg \alpha$. Goring et al. (1975) compared pesticide degradation processes using these rate equations. Walker (1976a,b) reported that the degradation of simazine, prometryne, and linuron herbicides in field soils followed first-order kinetics (i.e., n=1 in Eq. [5-1].

Among soil and environmental factors, soil temperature and soil-water content are the two most important factors that influence pesticide degradation rates in soils. Soil temperature and soil water-content influence soil microbial activity which, in turn, governs the biological degradation rate. Moreover, chemical and photochemical decomposition, and volatilization of pesticides are also affected by the changes of soil temperature and soil-water content. Walker (1974, 1976a,b, 1978a,b) used the relationship between degradation rate coefficient(k_1) and temperature, and rate coefficient and soil-water content to predict solvent-extractable parent chemical disappearance rates of a number of herbicides under field conditions. Assuming first-order kinetics, the half-lives or k_1 values for herbicides in soils under a range of controlled conditions can be expressed in two equations:

$$t_{1/2} = AM^{-B} \qquad [5\text{-}3]$$

$$\ln \frac{t'_{1/2}}{t''_{1/2}} = \frac{\Delta E}{R} \left[\frac{1}{T_1} - \frac{1}{T_2}\right] \qquad [5\text{-}4]$$

where, A and B are constants, $t_{1/2}$, $t'_{1/2}$, and $t''_{1/2}$ are half-lives at temperatures T, T_1, and T_2, respectively, M is soil moisture content ΔE is Arrhenius activation energy constant, and R is gas constant (1.984×10^{-3} kcal/mole-deg). Using these relationships, Walker and coworkers simulated herbicide disappearance rate in the field with a fair success. Predicted values were generally higher than observed values. Smith and Walker (1977) developed an empirical expression that describes the dependence of pesticide degradation rates on soil temperature plus soil-water coefficient. They assume a linear increase in the rate coefficient (k_1) with increasing value of the product (M * T), where M is the soil-water content, and T is soil temperature. This relationship can be stated as follows:

$$k_1 = \alpha MT + \beta \qquad [5\text{-}5]$$

where, α and β are empirical constants specific to a given pesticide, but not necessarily for a given soil type. Smith and Walker (1977) used Eq. [5-5] to successfully describe herbicide asulam degradation under field conditions. Given the vast complexity of the soil-water-pesticide systems, approaches given by Eq. [5-5] may be sufficiently accurate to describe the pesticide degradation rate dependence on soil temperature and soil-water content.

Pesticide degradation rates under field conditions have generally been measured as the rate of disappearance of organic solvent-extractable parent compound. Few reports include quantitative data on rates of metabolite accumulation from pesticide degradation in soils. Two specific drawbacks should be kept in mind when organic solvent-extractable parent compound disappearance rate is used as a measure of pesticide degradation. First, even though the parent compound itself may have degraded, significant amounts of various metabolites may accumulate. Some of these metabolites could be equally or more toxic and/or persistent in soils. Secondly, a significant portion of the parent compound and/or its metabolites may become "bound" to the soil. Consequently, in such cases the degradation rate measured from disappearance of parent compound would over-estimate the true degradation rate. An

TYPING GUIDE SHEET

alternate method of measuring pesticide degradation rate in soils, under laboratory incubation conditions, has been to monitor the rate of $^{14}CO_2$ evolution from soils incubated with ^{14}C-labeled pesticides. Depending upon the specific position of the ^{14}C-label on the pesticide molecule, $^{14}CO_2$ evolution rate may or may not represent the total mineralization rate. The mineralization rate measured using ^{14}C-ring labeled compounds is generally lower than parent compound disappearance rates.

BOUND PESTICIDE RESIDUES

In most studies dealing with persistance of pesticides in soils, the pesticide residual level remaining in the soil has been measured by extraction with organic solvents. However, use of ^{14}C-labeled pesticides in these experiments has revealed that losses from degradation and volatilization plus the ^{14}C-labeled pesticide extracted by organic solvents could not account for 100% of the added ^{14}C-pesticide. A substantial fraction of applied pesticide was apparently bound to the soil and could not be recovered by exhaustive extraction with organic solvents. The amount of bound pesticide residues is, therefore, determined by combusting a soil sample after exhaustive solvent extraction and quantifying the carbon dioxide produced.

Over the last few years considerable attention has been given to bound pesticide residues. The most comprehensive work has taken the form of the book entitled "Bound and Conjugated Pesticide Residues" edited by Kaufman et al. (1976). This review is a compilation of papers presented at a symposium sponsored by the Pesticide Chemistry Division of the American Chemical Society. A working definition of a soil-bound pesticide residue is "that unextractable and chemically unidentifiable pesticide residue remaining in fulvic acid, humic acid, and humin fractions of the soil after exhaustive sequential extraction with nonpolar and polar organic solvents."

The presence of these bound residues has focused new attention on pesticides persistance. Pesticides previously classified as nonpersistant in soils may actually be more persistant than originally thought. Johnson and Stansbury (1965) reported that the half-life of carbaryl insecticide in soil was about 8 days and that this insecticide was totally degraded within 40 days. However, Kazano et al. (1972) reported that substantial amounts (ranging from 20 to 60% of the original radioactivity) of the ^{14}C-carbaryl remained in the soil even after 32 days of incubation. Bartha (1971) and Chiska and Kearny (1970) found the bound residues of herbicide propanil to range from 50 to 80% of that applied. Similar findings for fonofos were reported by Flashinski and Lichtenstein (1974). Ambrosi et al. (1977) have studied the persistance and metabolism of the organo-phosphate insecticide phosalone in two soils, and found rapid disappearance of this pesticide to be accompanied by a large build-up of bound residues.

The amount of bound pesticide residues appears to increase with time (Katan et al., 1976; Lichtenstein et al., 1977). The bound residues gradually reached about 40, 10, 35, and 30%, respectively, for methyl parathion, dieldrin, dyfonate, and DDT during a 28 day incubation (Lichtenstein et al., 1977). The exact mechanisms for pesticide binding in soils are not well understood at this time. The binding of parathion and propanil apparently

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

involves soil microorganisms. The amount of bound residues declined drastically in sterile soils and also at low temperatures (Chiska and Kearny, 1970; Katan et al., 1976). However, binding of fonofos did not depend upon soil microbial activity (Lichtenstein et al., 1977). Soil organic matter also appears to play an important role in pesticide binding to soils. The amount of bound pesticide residue was higher in soils with a higher organic matter content than in those soils containing a low organic matter content (Katan et al., 1976). Furthermore, a majority of bound carbaryl residue was found to be linked to humic substances (Kazano et al., 1972). Fractionation of the bound residues of phosalone insecticide showed (Ambrosi et al., 1977) that the distribution of ^{14}C decreased in the order of fulvic acid > humic acid > humin; under flood conditions, however the ^{14}C distribution was altered to fulvic acid > humin > humic acid. Based on such findings, a two-step binding mechanism based on a microbial process and a physical-chemical process that leads to a strong covalent-type bonding of pesticides through organic substances in soil have been postulated (Katan et al., 1976; Hsu and Bartha, 1976).

ESTIMATING PESTICIDE DEGRADATION AND MINERALIZATION RATES

In this review, pesticides were divided into three main classes based on their agricultural use: herbicides, insecticides and fungicides. Chemicals within each class were subdivided into groups according to their chemical structure. For example, herbicides were grouped as phenoxyalkanoic acids, dinitroanilines, and s-triazines while insecticides were grouped as carbamates, chlorinated hydrocarbons, and organophosphates. Because of the number of chemicals and the volume of literature available, only pesticides which were now in wide use or were used widely in the past were considered. Chemicals with structural similarities tend to have similar physicochemical properties and exhibit similar biological responses. Hence, degradation rates in soils for the chemicals not listed in this review can be estimated using the data for structurally related compounds. Degradation rate constants were reported, if already shown in the literature. However, the majority of the literature did not provide rate constants and/or half-lives. In these cases, rate constants and half-lives for pesticides in soils were calculated by the reviewers assuming that degradation followed first-order kinetics. The following equations were used to calculate rate coefficients and/or half-lives:

$$\ln \frac{C_1}{C_2} = k_1 \ (t_2 - t_1) \qquad [5\text{-}6]$$

$$t_{1/2} = \frac{0.693}{k_1} \qquad [5\text{-}7]$$

Where C_1 and C_2 are pesticide concentrations at time t_1 and t_2 (days), k_1 is rate constant (day^{-1}), and $t_{1/2}$ is half life (days). Attempts were not made to calculate k_1 and $t_{1/2}$ for pesticide degradation rates which were originally expressed in regression equation form. Rate constants for each pesticide were divided into aerobic and anaerobic (including flooded with water) incubation. Rate constants and half-lives from laboratory studies were expressed in two ways: (1) as solvent-extractable parent-chemical disappearance rates and

EPA-287 (Cin.)
(4-76)

(2) mineralization rates. In attempts to correlate key soil properties with pesticide degradation rates, the following properties were used: pesticides concentration, organic matter and clay content, pH, temperature, soil-water content, and soil depth (field studies only). These properties are listed along with calculated rate constants and half-lives. Arrhenius activation energy constants were listed if available.

The common and chemical name of each pesticide considered in this manuscript is presented in Table 5-1.

Herbicides

2,4-D and 2,4,5-T--

Phenoxyalkanoic acid herbicides 2,4-D and 2,4,5-T are widely used to control broad leaf weeds. Microbial degradation appears to be the major factor in the disappearance of 2,4-D and 2,4,5-T as well as other phenoxyalkanoic acid herbicides in soils and water. Some soil microorganisms can utilize 2,4-D as their sole source of energy. For example, 2,4,5-T was degraded to CO_2, H_2O and chloride by two mixed bacteria through cometabolism in the presence of a second carbon source (Ou and Sikka, 1977). Very little degradation has been shown to occur in sterile soils treated with either herbicide. Solvent extractable 2,4-D disappearance rates (k_1) in soils incubated in the laboratory under aerobic conditions were 2.1×10^{-2} to 1.7×10^{-1} day^{-1} with an average of $(6.6 \pm 4.9) \times 10^{-2}$ day^{-1} (Table B1). This corresponds to half lives of 4 to 34 days with an average of 16 ± 9 days. The 2,4-D degradation rate appeared to be related to total soil bacterial population which probably reflects the higher 2,4-D degrading bacteria population in these soils. Solvent-extractable 2,4-D disappearance rates at field sites were generally higher than these observed for laboratory studies. The half lives for 2,4-D in the field were < 1 to 15 days with an average of 5 ± 5 days. This corresponds to a k_1 of < 0.7 to 4.6×10^{-2} day^{-1} and an average of 3.6 ± 3.0 day^{-1} (Table B2). Solvent extractable 2,4-D disappearance rates in flooded soils, according to Yashida and Castro (1975), were not significantly different from those associated with aerated soils, i.e., 3.6×10^{-2} day^{-1} vs 5.0×10^{-2} day^{-1}.

The mineralization rates for 2,4-D in soils incubated in the laboratory under aerobic conditions receiving 50 ppm or less were in the range of 2.8×10^{-2} to 6.3×10^{-2} day^{-1} with an average of $(5.1 \pm 1.2) \times 10^{-2}$ day^{-1} (Table B3). The average rate coefficient corresponds to a half life of 11 to 25 days (15 ± 5 days). Both solvent extractable parent chemical disappearance rates and mineralization rates for 2,4-D under aerobic laboratory conditions were similar. This suggests that the disappearance of 2,4-D in soils was mainly due to complete degradation by the soil microorganisms.

The half lives for 2,4,5-T in soils in the laboratory were 14 to 64 days with an average of 33 ± 22 days. This corresponds to rate constants, k_1, of 1.1×10^{-2} to 5.0×10^{-2} day^{-1} with an average of $(2.9 \pm 1.5) \times 10^{-2}$ day^{-1} (Table B4). Solvent extractable 2,4,5-T disappearance rates in the field were 9.9×10^{-3} to 7.4×10^{-2} day^{-1} with an average of $(3.5 \pm 2.9) \times 10^{-2}$ (Table B5) which corresponds to half lives of 8 to 31 days with an average of 16 ± 11 days.

Table 5-1. Common and Chemical Names of Selected Pesticides.

Common Name	Chemical Name
Aldrin	1,2,3,4,10,10-Hexachloro-1,4,4a,5,8,8a-hexahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Atrazine	2-Chloro-4-ethylamino-6-isopropylamino-s-triazine
Bromacil	5-Bromo-3-sec-butyl-6-methyluracil
Captan	N-(Trichloromethylthio)-4-cyclohexene-1,2-dicarboximide
Carbaryl	1-Naphthyl N-methylcarbamate
Carbofuran	2,3,Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate
Chlordane	1,2,4,5,6,7,8,8-Octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindene (principal constituent)
2,4-D	2,4-Dichlorophenoxyacetic acid
Dalapon	2,2-Dichloropropionic acid
p,p'-DDT	1,1,1-Trichloro-2,2-bis(p-chlorophenyl) ethane
o,p'-DDT	1,1,1-Trichloro-2-(O-chlorophenyl)-2-(p-chlorophenyl) ethane
Diazinon	O,O-diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate
Dicamba	3,6-Dichloro-O-anisic acid
Dieldrin	1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-Octahydro-1,4-endo-exo-5,8-dimethanonaphthalene
Diquat	6,7-Dihydrodipyrido (1,2-a:2',1'-C) pyrazidinium ion
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea
Endrin	1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo-endo-5,8-dimethanonaphthalene
Glyphosate	N-(Phosphonomethyl) glycine
Fonofos	O-Ethyl S-phenyl ethylphosphorodithioate

Continued

Table 5-1. (Continued)

Common Name	Chemical Name
Heptachlor	1,4,5,6,7,8,8-Heptachloro-3a,7,7a-tetrahydro-4,7-methanoindene
Lindane	γ-1,2,3,4,5,6-Hexachlorocyclohexane
Linuron	3-(3,4-Dichlorophenyl)-1-methoxy-1-methylurea
Malathion	S-[1,2-Bis(ethoxycarbonyl)ethyl]O,O-diethyl phosphorodithioate
Methylparathion	O,O-Dimethyl O-para-nitrophenyl phosphorothioate
Nitralin	4-Methylsulfonyl-2,6-dinitro-N,N-dipropylaniline
Paraquat	1,1'-Dimethyl-4,4'-bipyridylium ion
Parathion	O,O-Diethyl O-para-nitrophenyl phosphorothioate
PCP	Pentachlorophenol
Phorate	O,O-Diethyl-S-ethylthio methyl phosphorodithioate
Picloram	4-Amino-3,5,6-trichloropicolinic acid
Simazine	2-Chloro-4,6-bis(ethylamino)-s-triazine
2,4,5-T	2,4,5-Trichlorophenoxyacetic acid
TCA	Trichloroacetic acid
Terbacil	3-Tert-butyl-5-chloro-6-methyluracil
Trifluralin	α,α,α-Trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine

Atrazine and Simazine--

Atrazine and simazine are widely used s-triazine herbicides in agriculture. Application rates of atrazine and simazine in field studies were generally in the range of 1 to 4.5 kg/ha (0.4 to 2 μg/g). Half lives for atrazine in the field ranged from 12 to 53 days with an average half life of 20 ± 11 days. Rate constants, k_1, were in the range of 1.3×10^{-2} to 5.8×10^{-2} day^{-1} with an average of $(4.2 \pm 1.4) \times 10^{-2}$ day^{-1} (Table B6). Half lives and k_1 values were calculated based on first-order kinetics. Half lives and k_1 for simazine in the field were 11 to 246 days (64 ± 60 days) and 2.8×10^{-3} to 6.2×10^{-2} day^{-1} [$(2.2 \pm 2.1) \times 10^{-2}$ day^{-1}], respectively (Table B7). Walker (1976a) reported that simazine degradation in his soil appeared to follow first-order kinetics, as well as Michaelis-Menten enzyme kinetics.

Solvent-extractable atrazine disappearance rates in soils incubated in the laboratory tended to be higher than under field conditions. Half lives and k_1 values for atrazine under aerobic laboratory incubation were in the range of 24 to 109 days (48 ± 33 days) and 6.3×10^{-3} to 2.9×10^{-2} day^{-1} [$(1.9 \pm 0.9) \times 10^{-2}$ day^{-1}], respectively (Table B8). Incubation temperatures were 13.2 to 31.2°C. Half lives were shortened as the incubation temperature increased. Half lives at 13.2°C and 31.2°C were 109 and 35 days, respectively (Zimdahl, et al., 1970). Half lives at 95°C were less than 3 days (Hance, 1969). Solvent extractable simazine disappearance rates and half lives in soils held under conditions of aerobic laboratory incubation were 16 to 234 days (75 ± 55 days) and 3.0×10^{-3} to 4.3×10^{-2} day^{-1}, respectively [$(1.4 \pm 1.0) \times 10^{-2}$ day^{-1}]. Arrhenius activation energy constants for atrazine and simazine were 10.8 and 9.2 to 13.7 kcal/mole, respectively (Walker, 1976a,b; Zimdahl et al., 1970).

Mineralization rates for atrazine in soils were much lower than the solvent extractable parent chemical disappearance rates. In fact, mineralization rates for ^{14}C-ring labeled atrazine were 2.0×10^{-4} to 6.7×10^{-5} day^{-1} corresponding to half lives of 3,465 to 10,343 days (Table B10). No information regarding simazine mineralization rates was reported.

Trifluralin and Nitralin--

Dinitroaniline herbicides, trifluralin and nitralin are generally incorporated into a soil for preemergence control of specific grasses and broadleaf weeds. Trifluralin concentrations used in laboratory studies were in the range of 1 to 10 μg/g. At these concentrations, the solvent-extractable trifluralin disappearance rates in soils under aerobic incubation generally followed first-order kinetics, and the half lives and rate constants were in the range of 33 to 375 days (132 ± 109 days) and 1.8×10^{-3} to 2.1×10^{-2} day^{-1} (Table B11), respectively [$(8.4 \pm 5.5) \times 10^{-3}$ day^{-1}]. Arrhenius activation energy constants were 14.9 to 16.5 Kcal/mole. Under anerobic incubation, including flooded conditions, solvent-extractable trifluralin disappearance rates were generally higher than under aerobic incubation, and were in the range of 9.9×10^{-3} to 2.0×10^{-1} day^{-1} (Table B12). This corresponds to half lives of 4 to 70 days (average 28 days). Increasing temperature and soil moisture enhanced trifluralin volatilization in soils which enhanced the solvent extractable trifluralin disappearance rate. Mineralization rates for ^{14}C-labeled trifluralin (labeled at $-CF_3$) were very low and were in the range of 1.0 x 10^{-3} to 1.7 x 10^{-3} day^{-1} corresponding to 405 to 683 days with an average of 544 days (Messersmith et al., 1971). Solvent extractable trifluralin disappearance rates in field soils generally followed first-order kinetics, and were in the range of 1.0 x 10^{-2} to 4.7 x 10^{-2} day^{-1} (Table B13) [(2.0 ± 1.3) x 10^{-2} day^{-1}] corresponding to 15 to 69 days (46 ± 19 days). It was reported recently that solvent extractable trifluralin disappearance rates followed complex first-order kinetics better than simple first-order kinetics (Lafleur et al., 1978; Zimdahl and Gwynn, 1977).

No reliable quantitative degradation data could be used for computing nitralin degradation rates in soils. However, it was found that nitralin was persistent in soils which had a high organic matter content and neutral pH (Miller et al., 1976; Savage, 1973).

Bromacil and Terbacil--

Bromacil and terbacil are common substituted uracil herbicides. The average solvent extractable bromacil rate constant, k_1, for soils incubated in the laboratory under aerobic conditions was (7.7 ± 3.8) x 10^{-3} day^{-1} (Table B14) corresponding to a half life of 106 ± 45 days. The average solvent extractable terbacil rate constant under aerobic laboratory incubation was (1.5 ± 0.5) x 10^{-2} day^{-1} (Table B15). The average half life was 50 ± 13 days. Arrhenius activation energies for bromacil and terbacil were 3.0 and 6.1 cal/mole, respectively. The degradation rates for bromacil and terbacil, especially for bromacil, were not increased substantially by elevated temperatures. Mineralization rates for bromacil and terbacil from two reports were varied [4.6 x 10^{-3} vs 4.2 x 10^{-4} day^{-1} (Table B16) for bromacil, and 8.5 x 10^{-3} vs 5.4 X 10^{-4} day^{-1} (Table B17) for terbacil]. Mineralization rates for bromacil and terbacil were lower than solvent extractable parent chemical degradation rates, especially for terbacil. This indicated that volatilization, chemical degradation, photodecomposition and binding may contribute significantly to the disappearance of these chemicals from soils.

It appeared that solvent extractable bromocil and terbacil disappearance rates in the field followed complex first-order kinetics (Gardiner et al., 1969). The disappearance rate constants for bromacil and terbacil in the field during the first five weeks were 1.1 x 10^{-2} and 9.2 x 10^{-3} day^{-1}, and thereafter were 4.0 x 10^{-3} and 5.3 x 10^{-3} day^{-1}, respectively (Tables B18 and B19). By using simple first-order kinetics, the average rate constants for bromacil and terbacil were (3.8 ± 3.8) x 10^{-3} and (6.0 ± 3.3 x 10^{-3} day^{-1}. These values correspond to half lives of 349 ± 268 and 175 ± 155 days, respectively.

Diuron and Linuron--

Diuron and linuron are substituted urea herbicides used as selective pre- and post-emergence herbicides. Solvent extractable linuron disappearance rate constants for soils from laboratory studies under aerobic conditions were in the range of 2.4 x 10^{-3} to 1.2 x 10^{-2} day^{-1} (Table B20). With an average of (9.6 ± 1.9) x 10^{-3} day^{-1}. This corresponds to half lives of 56 to 88 days with an average of 75 ± 14 days. The incubation temperatures for the degradation rates reported above were 20°C or higher than 20°C. Decreases in temperature and moisture content resulted in decreasing degradation rates.

(Usorol and Hance, 1974). The Arrherius activation energy constants for linuron were in the range of 10.9 to 13.1 kcal/mole. The average solvent extractable linuron disappearance rate constant under field conditions in one report (Smith and Edmond, 1975) was $(3.4 \pm 1.4) \times 10^{-3}$ day^{-1} (Table B21) which corresponds to an average half life of 230 ± 88 days.

Solvent extractable diuron disappearance rate constants in the field were in the range of 1.3×10^{-3} to 5.2×10^{-3} day^{-1} (Table B22) with an average of $(3.1 \pm 1.8) \times 10^{-3}$ day^{-1} corresponding to half lives 133 to 657 days with an average of 328 ± 212 days. No degradation rates for diuron from laboratory studies could be obtained or derived. Reports for diuron degradation in field soils were primarily bioassays for determining pesticide residues. By comparing the average solvent extractable linuron disappearance rate in the field, it appears that the solvent extractable diuron disappearance rate in laboratory experiments would be somewhat lower than that for linuron.

Dicamba--

Dicamba, a benzoic acid herbicide, is used as a selective herbicide for pre- and post-emergence control of annual broadleaf and grassy weeds in cereals. The half lives for dicamba disappearance from soils incubated in the laboratory under aerobic conditions were in the range of ~0 to 32 days with an average of 14 ± 12 days. This corresponds to solvent extractable dicamba disappearance rate constants of 2.2×10^{-2} to $\sim \infty$ day^{-1} (Table B23). Even though dicamba rapidly disappeared from soils, especially at field capacity moisture levels (Smith, 1973) and for temperatures above 15°C (Smith and Cullimore, 1975), mineralization rates were much lower with half lives of 309 days for ^{14}C-ring labeled dicamba and 147 days for ^{14}C-carboxy-labeled dicamba. Substantial amounts of the metabolite 3,6-dichlorosalicylic acid were accumulated in soils (Smith, 1974). The Arrhenius activation energy was calculated to be 17.1 ± 6.1 kcal/mole for the temperature range 10° to 30°C. Degradation rates from 30 to 40°C were either the same or lower (Smith and Cullimore, 1975). No anerobic incubation studies were reported.

Solvent extractable dicamba disappearance rate constants for field conditions were in the range of 7.2×10^{-2} to 1.0×10^{-1} day^{-1} with an average of $(9.3 \pm 1.5) \times 10^{-2}$ day^{-1} (Table B24) corresponding to half lives 6 to 10 days (8 ± 1 day).

Picloram--

Picloram is a substituted picolinic acid herbicide and is the only prominant member of the family of pyridine derivatives that has been studied extensively. The solvent extractable picloram disappearance rate constants for soils incubated in the laboratory under aerobic conditions were in the range of 3.8×10^{-4} to 2.4×10^{-2} day^{-1} (Table B25) with an average of $(6.9 \pm 4.5) \times 10^{-3}$ day^{-1} corresponding to half lives of 29 to 1,804 days with an average of 201 ± 312 days. Two of the degradation rate constants (out of 44) were extremely low. If these two rate constants were excluded, the average degradation rate constant would be $(7.3 \pm 4.3) \times 10^{-3}$ day^{-1} corresponding to an average half life of 138 ± 93 days. Microbial degradation appears to be the major process for the disappearance of picloram from soils since very little degradation occurred in sterile soils (Goring and Hamaker, 1971). Increasing organic matter and temperature as well as adequate moisture increased disappearance rates. Arrhenius activation energy was reported to be 4.5 to 6.3 kcal/mole (Meikle et al., 1973). Solvent extractable picloram disappearance rate constants under flooded conditions appeared to be the same as for those under aerobic conditions, i.e., 4.7×10^{-3} day^{-1} vs 4.3×10^{-3} day^{-1} (Yoshida and Castro, 1975). Mineralization rates under aerobic conditions were much lower than that of the disappearance rates. Mineralization rates for carboxy-C^{14}-labeled picloram in soils at temperatures of 15° to 30°C were in the range of 5.0×10^{-6} to 4.0×10^{-3} day^{-1} (Table B26) with an average of $(8.0 \pm 8.9) \times 10^{-4}$ day^{-1} corresponding to half lives of 175 to 69,300 days with an average of 8,600 ± 15,845 days. Because of this, it appeared that substantial amounts of picloram metabolites could be accumulating in soils, although this has not been reported.

The solvent extractable picloram disappearance rate constants in the field were in the range of 8.3×10^{-3} to 5.7×10^{-2} day^{-1} (Table B27) with an average of $(3.3 \pm 1.7) \times 10^{-2}$ day^{-1} corresponding to half lives of 12 to 84 days with an average of 31 ± 24 days.

Dalapon and TCA--

Dalapon and TCA are two common chlorinated aliphatic acid herbicides. According to Namdeo (1972), the average half life for dalapon in soil was 15 days corresponding to solvent extractable dalapon disappearance rate constants of 4.7×10^{-2} day^{-1} (Table B23). The solvent extractable TCA disappearance rate in soils greatly increased as soil moisture and organic matter contents increased (McGrath, 1976; Smith, 1974). Solvent extractable TCA disappearance rate constants in soils were in the range of 8.9×10^{-3} to 1.2×10^{-1} day^{-1} (Table B29) with an average of $(5.9 \pm 6.1) \times 10^{-2}$ day^{-1} corresponding to half lives 4 to 144 days with an average of 46 ± 55 days. Degradation was mainly microbial. The average solvent extractable TCA disappearance rate in the field, according to McGrath (1976) was 4.6×10^{-2} day^{-1} (Table B30) corresponding to a half life of 15 days.

Glyphosate--

Glyphosate is a broad spectrum post-emergence herbicide. Degradation of glyphosate in soils is mainly a microbial process. Very little glyphosate was degraded in sterile soil (Rueppel et al., 1977; Sprankle et al., 1975). Degradation rates including solvent extractable glyphosate disappearance rates and mineralization rates varied greatly from one soil to another depending upon soil type. The solvent extractable glyphosate disappearance rate constants were from 5.3×10^{-3} to 2.3×10^{-1} day^{-1} (Table B31) with an average of $(1.0 \pm 1.2) \times 10^{-1}$ day-1 corresponding to half lives from 3 to 130 days with an average of 38 ± 53 days. The mineralization rate constants for glyphosate were from 1.3×10^{-4} to 2.3×10^{-2} day^{-1} (Table B32) with an average of $(8.6 \pm 8.0) \times 10^{-3}$ day^{-1} corresponding to half lives of 30 to 5,177 days with an average of 903 ± 1,732 days. The mineralization rates for ^{14}C-glyphosate labeled at various positions were all about the same (Rueppel et al., 1977). Bound residues were formed and one metabolite, aminomethylphosphonic acid, was detected in soils (Normura and Hilton, 1977; Rueppel et al., 1977). No degradation data obtained in the field have been reported.

Diquat and Paraquat--

Diquat and paraquat are the two most important bipyridylum herbicides. They are used as salts, diquat as the dibromide and paraquat as the dichloride. Both diquat and paraquat are rapidly and completely adsorbed to soil particles. Even though a number of soil microorganisms including bacteria and fungi could utilize either herbicide as a nitrogen source or a sole carbon source in synthetic media (Burns and Audus, 1970; Baldwin et al., 1966; Tu and Bollen, 1968), the disappearance of the herbicides in soils was slow in soils. Strong adsorption to soil clays and organic matter apparently rendered them inaccessible to soil microorganisms. Although a few publications reported degradation of diquat and paraquat in soils, one report could be used for calculating disappearance rate constants (Fryer et al., 1975). The average solvent extractable paraquat disappearance rate in the field was 1.5×10^{-4} day^{-1} ($0 - 4.9 \times 10^{-4}$ day^{-1}) corresponding to a half life of 4,747 days. The solvent extractable paraquat disappearance rate constants for a sandy loam soil in laboratory were 9.3×10^{-4} to 2.2×10^{-3} day^{-1} with an average of 1.6×10^{-3} day^{-1} corresponding to half lives 316 to 743 days with an average of 487 days.

Insecticides

Parathion, Methylparathion and Diazinon--

Parathion, methylparathion and diazinon are the three most widely used organophosphorothioate insecticides. The insecticides can be hydrolyzed biologically or chemically in soils. However, the microbial hydrolysis rate is much higher than the chemical hydrolysis rate (Bro-Rasmussen et al., 1968; Kishk et al., 1976; Saltzman et al., 1976; Sethunathan and McRae, 1969; Yaron, 1975). Only microbial degradation leads to complete detoxication of the chemicals to CO_2, H_2O and simple inorganic phosphate. The solvent extractable parathion disappearance rate constants for soils under laboratory aerobic incubation were in the range of 5.0×10^{-3} to 3.3×10^{-2} day^{-1} (Table B33) with an average of $(2.1 \pm 1.4) \times 10^{-2}$ day^{-1} corresponding to half lives 18 to 78 days with an average of 35 ± 29 days. Parathion was degraded very slowly in air dry soils with an average half life of 244 ± 108 days (Mingelgrin and Yaron, 1974). Solvent extractable parathion disappearance rate constants in flooded soils were higher than in aerated soils, and were in the range of 3.2×10^{-2} to 4.3×10^{-1} day^{-1} (Table B34) with an average of $(1.1 \pm 1.2) \times 10^{-1}$ day^{-1} corresponding to half lives of 2 to 22 days with an average of 11 ± 7 days. The solvent extractable parathion disappearance rate constants in the field were in the range of 2.4×10^{-2} to 2.3×10^{-1} day^{-1} (Table B35) with an average of $(5.7 \pm 5.8) \times 10^{-2}$ day^{-1} corresponding to half lives of 3 to 29 days with an average of 18 ± 8 days. No mineralization rates for parathion in soils were reported. However, bacteria that completely degraded parathion to CO_2, and H_2O were isolated. (Munnecke and Hsieh, 1974; Siddaramappa et al., 1973).

The average solvent extractable methylparathion disappearance rate constants from two soils incubated aerobically in the laboratory was 1.6×10^{-1} day^{-1} (Table B36) corresponding to an average half-life of 5 days. The solvent extractable methylparathion disappearance rate constant in the field, according to Lichtenstein and Schulz (1964), was 4.6×10^{-2} day^{-1} corresponding to a half life of 15 days.

Substantial amounts of both ^{14}C-parathion and ^{14}C-methylparathion became bound to soils (Katan et al., 1976; Lichtenstein et al., 1977). If ^{14}C-activity bound to soil was considered to be parent chemical, the solvent extractable parent chemical disappearance rate will be lower. For example, the solvent extractable ^{14}C-parathion disappearance rate constant in Plano silt loam was 8.9×10^{-3} day^{-1}, but after taking into account the bound residue it was 5.0×10^{-3} day^{-1} (Katan et al., 1976). The solvent extractable ^{14}C-methylparathion disappearance rate constant in Plano silt loam was 9.5×10^{-2} day^{-1}, and when bound residues were considered the rate constant was 2.5×10^{-2} day^{-1} (Lichtenstein et al., 1977).

Solvent extractable diazinon disappearance rate constants in soils incubated in the laboratory under aerobic conditions were in the range of 5.6×10^{-3} to 1.0×10^{-1} day^{-1} (Table B37) with an average of $(2.3 \pm 2.5) \times 10^{-2}$ day^{-1} corresponding to half lives 7 to 125 days with an average of 48 ± 30 days. The average Arrhenius activation energy constant under aerobic conditions was 12.0 ± 1.8 kcal/mole (a calculated value in Getzin, 1968). The mineralization rate constant in soil incubated under aerobic conditions, was 2.2×10^{-2} corresponding to a half life 32 days (Getzin, 1967). A diazinon hydrolysis product, 2-isopropyl-4-methyl-6-hydroxy-pyrimidine was detected. Nonextractable ^{14}C-residues were formed steadily, and about 35% of the total ^{14}C-activity was bound to Sultan silt loam in 16 weeks. Diazinon disappeared rapidly from flooded soils, the solvent extractable diazinon disappearance rate constants were 4.0×10^{-2} to 2.0×10^{-1} day^{-1} (Table B38) with an average of $(9.6 \pm 6.1) \times 10^{-2}$ day^{-1} corresponding to half lives 4 to 17 days with an average of 10 ± 5 days. However, mineralization rates in flooded soils were very low with an average of $(1.1 \pm 0.3) \times 10^{-4}$ day^{-1} corresponding to a half life of 6,833 ± 1,858 days (Sethunathan and McRae, 1969; Sethunathan and Yoshida, 1969). This discrepancy indicated that significant amounts of metabolites could be accumulating in the flooded soils. In fact, over 30% of metabolites 2-isopropyl-4-methyl-6-hydroxypyrimidine were detected after 9 days of incubation (Laanio et al., 1972). No degradation rates for field cases were reported.

Fonofos, Malathion and Phorate--

Fonofos, malathion and phorate are commonly used organodithiophosphorus insecticides. The solvent extractable fonofos disappearance rate constant for a soil incubated in the laboratory under aerobic conditions was 2.8×10^{-2} day^{-1} corresponding to a half life of 25 days (Lichtenstein et al., 1977). Bound residues from ^{14}C-labeled fonofos were rapidly formed in soil, and 35% of the applied ^{14}C-activity was non-extractable after 28 days. Solvent extractable fonofos disappearance rates in the field appeared to follow complex first-order kinetics--an initial rapid, disappearance followed by a slower disappearance rate. Average $t'_{1/2}$ and $t''_{1/2}$ values (Kiigemgi and Terriere, 1971; Schutz and Lichtenstein, 1971) were 24 and 102 days (Table B39), respectively. If simple first-order kinetics were employed, the average solvent extractable fonofos disappearance rate constant was 1.2×10^{-2} day^{-1} (Table B40) corresponding to a half life 60 days.

Microbial degradation and chemical hydrolysis are the two main factors contributing to the disappearance of malathion from soils and water. Chemical hydrolysis increased as pH increased (Konrad et al., 1969; Walker and Stojanovic, 1973). Malathion disappearance was much more rapid in nonsterile soils than in sterile soils. Solvent extractable malathion disappearance rate constants in nonsterile soils were in the range of 3.3×10^{-1} to 2.5 day^{-1} (Table B41) with an average of 1.4 ± 1.0 day^{-1} corresponding to half lives of 0.2 to 2.1 days with an average of 0.8 ± 0.7 day. Malathion also disappeared rapidly in water and sediment with half lives of 3 and 2 days, respectively (Walker, 1976).

Solvent extractable phorate disappearance rate constants in soils in the laboratory under aerobic conditions varied greatly (Getzin and Chapman, 1960; Getzin and Shank, 1970), $(8.9 \pm 1.2) \times 10^{-2}$ day^{-1} vs 8.4×10^{-3} day^{-1} (Table B42). The difference may be due to the analytical methods used since the average solvent extractable phorate disappearance in the field was $(1.0 \pm 0.3) \times 10^{-2}$ day^{-1} (7.9×10^{-3} to 1.4×10^{-2} day^{-1} (Table B43) corresponding to an average half life of 75 ± 18 days. GC was used for all field studies, and the half life of 82 days reported in one of the laboratory studies also used GC for analysis.

Carbaryl and Carbofuran--

The methylcarbamate insecticides carbaryl and carbofuran are broad spectrum systematic pesticides. The degradation rate for carbofuran in soils appears to increase as the soil pH increases and organic matter content decreases (Caro et al., 1973; Getzin, 1973). The solvent extractable carbofuran disappearance rate constants in soils incubated in the laboratory under aerobic conditions were in the range of 7.5×10^{-3} to 1.1×10^{-1} with an average of $(4.7 \pm 4.1) \times 10^{-2}$ day^{-1} (Table B44) corresponding to half lives of 6 to 93 days with an average of 37 ± 35 days. The average solvent extractable carbofuran disappearance rate constant in flooded soils was $(2.6 \pm 1.3) \times 10^{-2}$ (Table B45) corresponding to an average half life 44 ± 42 days (Venkateswarlu et al., 1977). The degradation rate decreased as soil pH decreased and organic matter content increased. The solvent extractable carbofuran disappearance rate in a flooded soil was lower than that in an aerated soil which had a pH above 5. The solvent extractable carbofuran disappearance rate constants for the field were in the range of 5.9×10^{-3} to 2.2×10^{-2} day^{-1} (Table B46) with an average of $(1.6 \pm 1.4) \times 10^{-2}$ day^{-1} corresponding to half lives 31 to 117 days with an average of 68 ± 42 days. The average mineralization rate constant for ^{14}C-labeled carbofuran (Getzin, 1973) was 1.3×10^{-3} day^{-1} (Table B47), corresponding to a half life of 535 days. Carbofuran phenol was the major metabolite found in soils.

Solvent extractable ^{14}C-carbonyl labeled carbaryl disappearance rate constants for soils held under aerobic conditions in the laboratory were 2.1×10^{-2} to 7.3×10^{-2} day^{-1} (Table B48) with an average of $(3.7 \pm 2.1) \times 10^{-2}$ day^{-1} corresponding to half lives 9 to 34 days with an average of 22 ± 9 days (Kazano et al., 1972). In the same report, mineralization rate constants were 9.5×10^{-4} to 1.4×10^{-2} day^{-1} with an average of $(6.3 \pm 6.4) \times 10^{-3}$ day^{-1} corresponding to half lives 51 to 728 days with an average of 309 ± 284 days. The mineralization rate constants may not represent the total ring structure breakdown, since the position of ^{14}C was on the side chain. Solvent extractable carbaryl disappearance rate constants for the field were 2.8×10^{-2} to 1.9×10^{-1} day^{-1} (Table B49) with an average of $(10.0 \pm 8.0) \times 10^{-2}$ day^{-1}

corresponding to half lives 4 to 25 days with an average of 12 ± 11 days. However, some of the data were derived using an analytical method which converts carbaryl to α-naphthol prior to measurement (Johnson and Stansbury, 1965). Thus, this method would not be able to differentiate between the α-naphthol already present as a result of metabolism and the α-naphthol derived from the hydrolysis of carbaryl. One report indicated a 40-day lag phase (Caro et al., 1974).

DDT, Aldrin, Dieldrin, Endrin, Chlordane, Heptachlor and Lindane--

DDT, aldrin, dieldrin, endrin, chlordane, heptachlor and lindane were widely used chlorinated hydrocarbon insecticides several years ago. This group of insecticides is generally very persistent in the environment, and their half lives in soils are generally over one year.

DDT is the representative chemical of the chlorinated hydrocarbon insecticides. Two major metabolites of DDT are DDD (1,1-dichloro-2,2-bis(p-chlorophenyl)ethane) and DDE (1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene). DDD and DDE are as toxic and persistent as the parent chemical DDT. Therefore, the solvent extractable parent chemical disappearance rates reflect the combined disappearance of DDE, DDD and DDT. Solvent extractable DDT disappearance rate constants were in the range of 1.2×10^{-4} to 6.5×10^{-3} day^{-1} (Table B50) with an average of $(1.3 \pm 1.7) \times 10^{-4}$ day^{-1} corresponding to half lives 106 to 5,675 days with an average of 1,657 ± 1,629 days. Under anaerobic conditions, DDT disappeared rapidly from soils while the concentration of metabolites increased. The DDT disappearance rate increased as the incubation temperature increased (Guenzi and Beard, 1976). Solvent extractable DDT disappearance rate constants for anaerobic soils at temperatures below 40°C were 3.6×10^{-4} to 7.3×10^{-3} day^{-1} (Table B51) with an average of $(3.5 \pm 2.9) \times 10^{-3}$ day^{-1} corresponding to an average half life of 692 ± 854 days. Bound residues (up to 34% of total ^{14}C-activity) were formed in ^{14}C-DDT treated soils under aerobic and anaerobic incubation (Guenzi and Beard, 1976; Lichtenstein et al., 1977).

Degradation rates in soils for aldrin and dieldrin were reported together, since their physiochemical characteristics are similar. The solvent extractable aldrin and dieldrin disappearance rate constants for the field cases were 7.0×10^{-5} to 9.6×10^{-3} day^{-1} (Table B52) with an average of $(2.3 \pm 2.3) \times 10^{-3}$ day^{-1} corresponding to an average half life of 1,237 ± 2,454 days. The solvent extractable aldrin and dieldrin disappearance rate constants for soils under laboratory aerobic incubation conditions reported by Lichtenstein et al. (1977) and Lichtenstein and Schulz (1959) appeared to be higher than that from the field soils, 1.3×10^{-2} (Table B53) vs 2.3×10^{-3} day^{-1}.

According to one report (Guenzi et al., 1971), solvent extractable endrin disappearance rate constants for fields under flooded or nonflooded conditions were 5.3×10^{-3} and 1.5×10^{-3} day^{-1} (Table B54) corresponding to half lives 130 and 468 days, respectively. The average solvent extractable endrin disappearance rate constant in flooded soils under laboratory studies was $(3.0 \pm 1.6) \times 10^{-2}$ (Table B55), corresponding to an average half life of 31 ± 19 days.

The average half life for chlordane (α and γ isomers) in the field was about the same as that for aldrin and dieldrin, (1,214 ± 2,453 days) and solvent extractable chlordane disappearance rate constants were in the range of 6.9×10^{-5} to 8.0×10^{-2} day^{-1} (Table B56) with an average of $(2.4 \pm 2.5) \times 10^{-3}$ day^{-1}.

Solvent extractable heptachlor disappearance rate constants for field cases were 7.8×10^{-3} to 1.4×10^{-2} day^{-1} (Table B57) with an average of $(4.6 \pm 5.5) \times 10^{-3}$ day^{-1} corresponding to an average half life of 426 ± 352 days. The average half life for heptachlor in soils incubated aerobically in the laboratory was 63 days (Table B58) (Lichtenstein and Schutz, 1959).

Solvent extractable lindane disappearance rate constants for field cases were in the range of 6.0×10^{-4} to 7.9×10^{-3} day^{-1} (Table B59) with an average of $(2.4 \pm 1.9) \times 10^{-3}$ day^{-1} corresponding to half lives 88 to 1,146 days with an average of 450 ± 280 days. Solvent extractable lindane disappearance rate constants for soils under laboratory aerobic and flooded conditions (Mathur and Saha, 1977) were 2.6×10^{-3} (Table B60) and 4.6×10^{-3} day^{-1} (Table B61) corresponding to half lives of 276 and 174 days, respectively.

Fungicides

PCP and Captan--

PCP (pentachlorophenol) is used as a wood preservative, and until a few years ago, it was a major herbicide used in rice paddy fields. PCP disappears in soils and water by chemical, microbiological and photochemical processes. Numerous soil fungi and bacteria degrade PCP, and numerous chlorinated phenols from mono- to tetra-chlorinated phenols were detected in PCP treated soils (Kaufman, 1976, 1978). Microbial degradation appeared to be the most important factor for the disappearance of PCP from soils. No degradation was found in sterile soil (Watanabe, 1978). Solvent extractable PCP disappearance rate constants for flooded soils were much higher than those for aerobic soils. Solvent extractable PCP disappearance rate constants for flooded soils were in the range of 1.1×10^{-2} to 1.2×10^{-1} day^{-1} (Table B62) with an average of $(7.0 \pm 3.1) \times 10^{-2}$ day^{-1}, corresponding to half lives 6 to 64 days with an average of 15 ± 15 days. Whereas, the solvent extractable PCP disappearance rate constant under aerobic conditions, according to one report (Kauwatsuka and Igarashi, 1975), was 7.1×10^{-3} to 3.9×10^{-2} day^{-1} (Table B63) with an average of $(2.0 \pm 1.2) \times 10^{-2}$ day^{-1} corresponding to half lives 18 to 97 days with an average of 48 ± 29 days. The solvent extractable PCP disappearance rate constant for a field case in one report (Watanabe, 1977) was higher than 5.0×10^{-2} day^{-1}, corresponding to a half life of less than 14 days.

Captan is a widely used chlorinated hydrocarbon fungicide. No reports were found describing the use of chemical analyses for determining captan residues in soils. However, the half lives of captan using bioassays appeared to be no more than 3 days (Agnihotri, 1971; Griffith and Mattews, 1969).

SUMMARY

A summary of the data presented in the Appendix (Tables B1-B63) is given in Table 5-2. The k and $T_{1/2}$ values computed using field data are based on the disappearance of the parent compound (solvent-extractable). Rate coefficients and half-lives calculated on the basis of mineralization ($^{14}CO_2$ evolution) as well as solvent-extractable parent compound disappearance under laboratory conditions are also included. Unless otherwise specified, the laboratory studies were performed under aerobic conditions and involved measurement of $^{14}CO_2$ evolution from ^{14}C-ring labeled compounds. The means and coefficient of variation values for k and $t_{1/2}$ are shown in Table 5-2. In most cases, the half-lives of pesticides under field conditions are much lower than under laboratory conditions. This can be attributed to the fact that under field conditions a multitude of factors and processes contribute to the disappearance of the pesticide, while laboratory studies are generally designed to be conducted under controlled conditions. Coefficient of variation (% CV) values in Table 5-2 are less than 100% in a majority of the cases. Considering the range in soil and environmental conditions under which degradation was measured, the CV is rather small. Thus, the degradation rate can be estimated within a factor of 2-4 for most pesticides using data presently available.

The data presented in Table 5-3 consists of only $t_{1/2}$ values from laboratory (aerobic) studies rather than field data for the following reasons: (i) greater analytic reliability because of GC or ^{14}C-assay, and (ii) $t_{1/2}$ values from laboratory studies are generally smaller and provide more conservative estimates than field data. As shown in Table 5-3, most chlorinated hydrocarbons are grouped as persistent, while carboxyalkanoic acid herbicides are nonpersistent. s-triazines, substituted ureas, and carbamate pesticides are grouped as the moderately persistent compounds.

The half-lives of pesticides in soils varied over a wide range from less than a few days to more than a year (based on the solvent extractable parent chemical disappearance rates under aerobic conditions). Pesticides were placed into three groups based on their half-lives in soils (Table 5-3): non-persistent ($t_{1/2} \leq 20$ days), moderately persistent ($20 \leq t_{1/2} \leq 100$ days) and persistent ($t_{1/2} \geq 100$ days). Pesticides in the first group (non-persistent) are readily biodegradable. Microbial degradation is the main factor in the disappearance of these chemicals in soils. Chemical degradation, photodecomposition and volatilization may contribute to the disappearance of these pesticides, but they are believed to be minor factors. Chemicals which fall into this group are 2,4-D, 2,4,5-T, dicamba, dalapon, methyl parathion, malathion, and captan. Microorganisms may be involved in the degradation of the second group (moderately persistent) of pesticides, since degradation rates in sterile soils were generally lower than those in non-sterile soils. However, soil microorganisms that extensively degrade these chemicals to CO_2, H_2O, and simple inorganic salts could not be isolated. It appears that microbial degradation of these compounds is due to cometabolism. Chemical degradation, photodecomposition, evaporation and binding may also play key roles in the disappearance of these chemicals from soils. Furthermore, significant amounts of metabolites may accumulate in soils because of microbial cometabolism, chemical degradation

Table 5-2. Degradation Rate Coefficients and Half-Lives for Several Pesticides under Laboratory and Field Conditions.

Pesticide		Rate Coeff. (day^{-1})		Half-Life (days)	
		Mean	%CV	Mean	%CV
A. HERBICIDES					
2,4-D	Lab.*	0.066	74.2	16	56.25
	Lab.	0.051	23.5	15	33.3
	Field	3.6	83.3	5	100.0
2,4,5-T	Lab.	0.029	51.7	33	66.7
	Lab.*	0.035	82.9	16	68.8
ATRAZINE	Lab.*	0.019	47.4	48	68.8
	Lab.	0.0001	70.4	6900	71.5
	Field	0.042	33.3	20	50.0
SIMAZINE	Lab.*	0.014	71.4	75	73.3
	Field	0.022	95.5	64	93.8
TRIFLURALIN	Lab.*	0.008	65.5	132	82.6
	Lab.* (anaerobic)	0.025	-	28	-
	Lab. (chain)	0.0013	-	544	-
	Field	0.02	65.0	46	41.3
BROMACIL	Lab.*	0.0077	49.4	106	42.5
	Lab.	0.0024	116.2	901	116.2
	Field	0.0038	100.0	349	76.8
TERBACIL	Lab.*	0.015	33.3	50	26.0
	Lab.	0.0045	124.0	679	124.5
	Field	0.006	55.0	175	88.6
LINURON	Lab.*	0.0096	19.8	75	18.7
	Field	0.0034	41.2	230	29.3
DIURON	Lab.	-	-	-	-
	Field	0.0031	58.1	328	64.6
DICAMBA	Lab.*	0.022	80.2	14	85.7
	Lab. (ring)	0.0022	-	309	-
	Lab. (chain)	0.0044	-	147	-
	Field	0.093	16.1	8	12.5

(Continued)

Table 5-2. (Continued)

Pesticide		Rate Coeff. (day^{-1})		Half-Life (days)	
		Mean	%CV	Mean	%CV
PICLORAM	Lab.*	0.0073	58.9	138	67.4
	Lab.	0.0008	111.3	8600	184.2
	Field	0.033	51.5	31	77.4
DALAPON	Lab.*	0.047	-	15	-
TCA	Lab.*	0.059	103.4	46	119.6
	Field	0.073	-	22	-
GLYPHOSATE	Lab.*	0.1	121.0	38	139.5
	Lab.	0.0086	93.0	903	191.8
PARAQUAT	Lab.*	0.0016	-	487	-
	Field	0.00015	-	4747	-
B. INSECTICIDES					
PARATHION	Lab.*	0.029	48.3	35	82.9
	Field	0.057	101.8	18	44.4
METHYL PARATHION	Lab.*	0.16	-	4	-
	Field	0.046	-	15	-
DIAZINON	Lab*	0.023	108.7	48	62.5
	Lab.	0.022	-	32	-
FONOFOS	Lab.*	0.012	-	60	-
MALATHION	Lab.*	1.4	71.4	0.8	87.5
PHORATE	Lab.*	0.0084	-	82	-
	Field	0.01	30.0	7.5	24.0
CARBOFURAN	Lab.*	0.047	87.2	37	94.6
	Lab.	0.0013	-	535	-
	Lab.* (anaerobic)	0.026	50.0	44	95.4
	Field	0.016	87.5	68	61.8

(Continued)

Table 5-2. (Continued)

Pesticide		Rate Coeff. (day^{-1})		Half-Life (days)	
		Mean	%CV	Mean	%CV
CARBARYL	Lab.*	0.037	56.8	22	40.9
	Lab. (chain)	0.0063	101.6	309	91.9
	Field	0.10	79.2	12	91.7
DDT	Lab.*	0.00013	130.8	1657	98.3
	Lab.* (anaerobic)	0.0035	82.9	692	123.4
ALDRIN and DIELDRIN	Lab.*	0.013	-	53	-
	Field	0.0023	100.0	1237	198.4
ENDRIN	Lab.* (anaerobic)	0.03	53.3	31	61.3
	Field (aerobic)	0.0015	-	460	-
	Field (anaerobic)	0.0053	-	130	-
CHLORDANE	Field	0.0024	104.2	1214	202.1
HEPTACHLOR	Lab.*	0.011	-	63	-
	Field	0.0046	119.6	426	82.6
LINDANE	Lab.*	0.0026	-	266	-
	Lab. (anaerobic)	0.0046	-	151	-
C. FUNGICIDES					
PCP	Lab.*	0.02	60.0	48	60.4
	Lab. (anaerobic)	0.07	44.3	15	100.0
	Field	0.05	-	14	-
CAPTAN	Field	0.231	-	3	-

*These rates are based on the disappearance of solvent-extractable parent compound under aerobic incubation conditions, unless stated otherwise.

Table 5-3. Grouping of Pesticides Based on Their Persistence* in Soils under Laboratory Incubation Conditions.

NON-PERSISTENT $t_{1/2} < 20$ days	MODERATELY PERSISTENT $20 \leq t_{1/2} \leq 100$ days		PERSISTENT $t_{1/2} > 100$ days
2,4-D	Atrazine	Phorate	Trifluralin
2,4,5-T	Simazine	Carbofuran	Bromacil
Dicamba	Terbacil	Carbaryl	Picloram
Dalapon	Linuron	Aldrin	Paraquat
Methyl Parathion	TCA	Dieldrin	DDT
Malathion	Glyphosate	Endrin	Chlordane
Captan	Parathion	Heptachlor	Lindane
	Diazinon	PCP	
	Fonofos		

---

*Persistence as determined by the rate of disappearance of the solvent-extractable parent compound under aerobic laboratory incubation conditions.

and photodecomposition. Unlike the first group of pesticides, solvent extractable parent chemical disappearance rates are generally much higher than mineralization rates. Mineralization rates in soils for the third group (persistent pesticides) are nearly zero, and there are generally no clear differences between solvent-extractable parent-chemical disappearance rates in sterile and non-sterile soils. Most of the chlorinated hydrocarbon insecticides belong to this group.

Even though a large number of literature citations describing the soil-mediated degradation of pesticides were reviewed, efforts failed to establish multiple regression equations which correlated degradation rates with soil properties. Part of the problem arises in that many reports fail to give soil physiochemical characteristics, incubation temperature and moisture tension. Soil organic matter content, moisture tension, and temperature appear to be important factors in the degradation of pesticides. These factors are also related to microbial activity.

REFERENCES FOR SECTION 5

Agnihotri, V. P. 1971. Persistence of captan and its effects on microflora, respiration, and nitrification of a forest nursery soil. Can. J. Microbiol. 17:377-383.

Altom, J. D. and J. F. Stritzke. 1973. Degradation of dicamba, picloram, and four phenoxy herbicides in soils. Weed Sci. 21:556-560.

Baldwin, B. C., M. G. Bray, and M. J. Curl. 1966. The microbial decomposition of paraquat. Biochem. J. 101:15.

Beynon, K. I., G. Stoydin, and A. N. Wright. 1972. A comparison of the breakdown of the triazine herbicides cyanazine, atrazine and simazine in soils and in maize. Pest. Biochem. Physiol. 2:153-161.

Bovey, R. W., C. C. Bowler, and M. G. Merkle. 1969. The persistence and movement of picloram in Texas and Puerto Rican soils. Pest. Monitoring J. 3:177-181.

Bro-Rasmussen, F., E. Noddegard, and K. Voldum-Clousen. 1968. Degradation of diazinon in soil. J. Sci. Food Agr. 19:278-281.

Burge, W. D. 1971. Anaerobic decomposition of DDT in soil. Acceleration by volatile components of alfalfa. J. Agr. Food Chem. 19:375-378.

Burns, R. G. and L. J. Audus. 1970. Distribution and breakdown of paraquat in soil. Weed Res. 10:49-58.

Caro, J. H., H. P. Freeman, D. E. Glottelty, B. C. Turner, and W. M. Edwards. 1973. Dissipation of soil incorporated carbofuran in the field. J. Agr. Food Chem. 21:1010-1015.

Caro, J. H., H. P. Freeman, and B. C. Turner. 1974. Persistence in soil and losses in runoff of soil-incorporated carbaryl in a small watershed. J. Agr. Food Chem. 22:860-863.

Clay, D. V. 1973. The persistence and penetration of large doses of simazine in uncropped soil. Weed Res. 13:42-50.

Cliath, M. M. and W. F. Spencer. 1971. Movement and persistence of dieldrin and lindane in soil as influenced by placement and irrigation. Soil Sci. Soc. Amer. Proc. 35:791-795.

Crosby, D. G. 1973. The fate of pesticides in the environment. Ann. Rev. Plant Physiol. 24:467-492.

Duseja, D. R. and E. E. Holmes. 1978. Field persistence and movement of trifluralin in two soil types. Soil Sci. 125:41-48.

Edwards, C. A. 1972. In Organic Chemicals in the Soil Environment, eds. Goring, C. A. I., and J. W. Hamaker, Vol. 2, pp. 515-568. Marcel Dekker, New York.

Foster, R. K. and R. B. McKercher. 1973. Laboratory incubation studies of chlorophenoxyacetic acids in chernozemic soils. Soil Biol. Biochem. 5:333-337.

Fryer, J. D., R. J. Hance and J. W. Ludwig. 1975. Long-term persistence of paraquat in a sandy loam soil. Weed Res. 15:189-194.

Gardiner, J. A., R. C. Rhodes, J. B. Adams, Jr., and E. J. Soboczenski. 1969. Synthesis and studies with 2-^{14}C-labeled bromacil and terbacil. J. Agr. Food Chem. 17:980-986.

Getzin, L. W. 1967. Metabolism of diazinon and zinophos in soils. J. Econ. Entomol. 60:505-508.

Getzin, L. W. 1968. Persistence of diazinon and zinophos in soil: Effects of autoclaving, temperature, moisture, and activity. J. Econ. Entomol. 61:1560-1565.

Getzin, L. W. 1973. Persistence and degradation of carbofuran in soil. Environ. Entomol. 2:461-467.

Getzin, L. W. and R. K. Chapman. 1960. The fate of phorate in soils. J. Econ. Entomol. 53:47-51.

Getzin, L. W. and C. H. Shark, Jr. 1970. Persistence, degradation, and bioactivity of phorate and its oxidative analogues in soil. J. Econ. Entomol. 63:52-58.

Gibson, W. P. and R. G. Burns. 1977. The breakdown of malathion in soil and soil components. Microbial Ecol. 3:219-230.

Glass, B. L. 1972. Relation between the degradation of DDT and the iron redox system in soils. J. Agr. Food Chem. 20:324-327.

Goring, C. A. I. and J. W. Hamaker. 1971. The degradation and movement of picloram in soil and water. Down to Earth 27(1):12-15.

Goswami, K. P. and R. E. Green. 1971. Microbial degradation of the herbicide atrazine and its 2-hydroxy analog in submerged soils. Environ. Sci. Technol. 5:426-429.

Gowa, T. K. S. and N. Sethunathan. 1976. Persistence of endrin in Indian rice soils under flooded conditions. J. Agr. Food Chem. 24:750-753.

Gowa, T. K. S. and N. Sethunathan. 1977. Endrin decomposition in soils as influenced by aerobic and anaerobic conditions. Soil Sci. 125:5-9.

Green, R. E., K. P. Goswami, M. Mukhtar, and H. Y. Young. 1977. Herbicide from cropped watersheds in stream and estuarine sediment in Hawaii. J. Environ. Quality 6:145-154.

Griffith, R. L. and S. Matthews. 1969. The persistence in soil of the fungicidal seed dressings captan and thiram. Ann. Appl. Biol. 64:113-118.

Guenzi, W. D. and W. E. Beard. 1976. Picloram degradation in soils as influenced by soil water content and temperature. J. Environ. Quality 5:189-192.

Guenzi, W. D. and W. E. Beard. 1976. DDT degradation in flooded soil on related to temperature. J. Environ. Quality 5:391-394.

Guenzi, W. D., W. E. Beard, and F. G. Viets, Jr. 1971. Influence of soil treatment on persistence of six chlorinated hydrocarbon insecticides in the field. Soil Sci. Soc. Amer. Proc. 35:910-913.

Hall, J. K. and N. L. Hartwig. 1978. Atrazine mobility in two soils under conventional tillage. J. Environ. Quality 7:63-68.

Hamaker, J. W. 1972. Decomposition: Quantitative aspects. In Organic Chemicals in the Environment, eds. Goring, C. A. I., and J. W. Hamaker. Marcel Dekker, New York.

Hance, R. J. 1969. Further observations of the decomposition of herbicides in soil. J. Sci. Food Agr. 20:144-145.

Hance, R. J. 1974. Soil organic matter and the adsorption and decomposition of the herbicide atrazine and linuron. Soil Biol. Biochem. 6:39-42.

Harris, C. R. and W. W. Sums. 1975. Persistence of velsicol HCS-3260 (AG-chlordane) in mineral and organic soil. Proc. Entomol. Soc. Ontario 106:34-38.

Helling, C. S., P. C. Kearney, and M. Alexander. 1971. Behavior of pesticides in soils. Adv. Agron. 23:147-240.

Hill, G. D., J. W. McGahen, H. M. Baker, D. W. Finnerty, and C. W. Bingeman. 1955. The fate of substituted urea herbicides in agricultural soils. Agron. J. 47:93-104.

Howard, P. H., J. Saxena, P. R. Durkins, and L.-T. Ou. 1975. Review and evaluation of available techniques for determining persistence and routes of degradation of chemical substances in the environment. USEPA.

Joshi, O. P. and N. P. Datta. 1975. Persistence and movement of simazine in soil. J. Indian Soc. Soil Sci. 23:263-265.

Johnson, D. P. and H. A. Stansbury. 1965. Adaptation of sevin insecticide (carbaryl) residue method to various crops. J. Agr. Food Chem. 13:235-238.

Katan, J., T. W. Fuhremann, and E. P. Lichtenstein. 1976. Binding of [^{14}C] parathion in soil: A reassessment by pesticide persistence. Science 193:891-894.

Kaufman, D. D. 1976. Phenols. In herbicides, pp. 665-707, eds. Kearney, P. C. and D. D. Kaufman. Marcel Dekker, Inc., New York.

Kaufman, D. D. 1976. Soil degradation and persistence of benchmark pesticides. In A Literature Survey of Benchmark Pesticides, pp. 19-71. USEPA.

Kaufman, D. D. 1978. Degradation of pentachlorophenol in soil, and by soil microorganisms. In Pentachlorophenol, pp. 27-39, ed. Rao, K. R., Plenum Press, New York.

Kauwatsuka, S. and M. Igarashi. 1975. Degradation of PCP in soils. II. The relationship between the degradation of PCP and the properties of soils, and the identification of the degradation products of PCP. Soil Sci. Plant Nutr. 21:405-411.

Kazano, H., P. C. Kearney, and D. D. Kaufman. 1972. Metabolism of methylcarbamate insecticides in soils. J. Agr. Food Chem. 20:975-979.

Kearney, P. C. and C. S. Helling. 1969. Reactions of pesticides in soils. Residue Rev. 25:25-44.

Kearney, P. C., J. R. Plimmer, W. B. Wheeler, and A. Konston. 1976. Persistence and metabolism of dinitroaniline herbicides in soils. Pest. Biochem. Physiol. 6:229-238.

Khan, S. U. 1977. Determination of terbacil in soil by gas-liquid chromatography with ^{63}Ni electron capture detection. Bull. Environ. Contamin. Toxicol. 18:83-88.

Khan, S. U. and P. B. Marriage. 1977. Residues of atrazine and its metabolites in an ochard soil and their uptake by oat plants. J. Agr. Food Chem. 25:1408-1414.

Khan, S. U., P. B. Marriage and W. J. Saidak. 1976. Persistence and movement of diuron and 3,4-dichloroaniline in an orchard soil. Weed Sci. 24:583-586.

Kiigemgi, U. and L. C. Terriere. 1971. The persistence of zinophos and dyfonate in soil. Bull. Environ. Contamin. Toxicol. 6:355-361.

Kishk, F. M., T. El-Essawi, S. Abdel-Ghafar, and M. B. Abou-Donia. 1976. Hydrolysis of methylparathion in soils. J. Agr. Food Chem. 24:305-307.

Konrad, J. G., G. Chester, and D. E. Armstrong. 1969. Soil degradation of malathion, a phosphorodithioate insecticide. Soil Sci. Soc. Amer. Soc. 33:259-262.

Kuhr, R. J., A. C. Davis, and J. B. Bourke. 1974. Dissipation of guthion, sevin, polyram, phygon and systox from apple orchard soil. Bull. Environ. Contamin. Toxicol. 11:224-230.

Laanio, T. L., G. Dupuis, and H. O. Esser. 1972. Fate of ^{14}C-labeled diazinon in rice, paddy soil, and pea plants. J. Agr. Food Chem. 20:1213-1219.

Lafleur, K. S., W. R. McCaskill, and G. T. Gale, Jr. 1978. Trifluralin persistence in Cangaree soil. Soil Sci. 126:285-289.

Lavegila, J. and P. A. Dahm. 1977. Degradation of organophosphorus and carbamate insecticides in the soil and by microorganisms. Ann. Rev. Entomol. 22:483-513.

Leistru, M., J. H. Smelt, and R. Zandvoort. 1975. Persistence and mobility of bromacil in orchard soils. Weed Res. 15:243-247.

Lichtenstein, E. P., L. J. DePew, E. L. Eshbaugh, and J. P. Sleesman. 1960. Persistence of DDT, aldrin, and lindane in some midwestern soils. J. Econ. Entomol. 53:136-142.

Lichtenstein, E. P., T. W. Fuhremann, and K. R. Schulz. 1971. Persistence and vertical distribution of DDT, lindane, and aldrin residues 10 and 15 years after a single soil application. J. Agr. Food Chem. 19: 718-721.

Lichtenstein, E. P., J. Katan, and B. N. Anderegg. 1977. Binding of "persistent" and "nonpersistent" ^{14}C-labeled insecticides in an agricultural soil. J. Agr. Food Chem. 25:43-47.

Lichtenstein, E. P. and K. R. Schulz. 1959. Breakdown of lindane and aldrin in soils. J. Econ. Entomol. 52:118-124.

Lichtenstein, E. P. and K. R. Schulz. 1959. Persistence of some chlorinated hydrocarbon insecticides as influenced by soil types, rate of application, and temperature. J. Econ. Entomol. 52:124-131.

Lichtenstein, E. P. and K. P. Schulz. 1964. The effects of moisture and microorganisms on the persistence and metabolism of some organophosphorus insecticides in soils, with special emphasis on parathion. J. Econ. Entomol. 57:618-627.

Lichtenstein, E. P., K. R. Schluz. T. W. Fuhremann, and T. T. Liaing. 1970. Degradation of aldrin and heptachlor in field soils during a 10 year period, translocation into crops. J. Agr. Food Chem. 18:100-106.

Lutz, J. F., G. E. Byers, and T. J. Sheets. 1973. The persistence and movement of picloram and 2,4,5-T in soils. J. Environ. Quality 4: 485-488.

Marriage, P. B., W. J. Saidak, and F. G. Von Stryk. 1975. Residues of atrazine, simazine, linuron, and diuron after repeated annual applications in a peach orchard. Weed Res. 15:373-379.

Mathur, S. P., H. A. Hamilton, R. Greenhalgh, K. A. Macmillan, and S. U. Khan. 1976. Effect of microorganisms and persistence of field-applied carbofuran and dyfonate in a humic meisol. Can. J. Soil Sci. 56:89-96.

Mathur, S. P. and J. G. Saha. 1977. Degradation of lindane-^{14}C in a mineral soil and in an organic soil. Bull. Environ. Contamin. Toxicol. 17:424-430.

Matsumura, F. 1974. In Survival in Toxic Environments, eds. Khan, M. A. Q. and J. P. Bederka, Jr., pp. 129-154. Academic Press, New York.

McGrath, D. 1976. Factors that influence the persistence of TCA in soil Weed Res. 16:131-137.

Meikle, R. W., E. A. Williams, and C. T. Redeman. 1966. Metabolism of tordon herbicide (4-amino-3,5,6-trichloropicolinic acid) in cotton and decomposition in soil. J. Agr. Food Chem. 14:384-387.

Meikle, R. W., C. R. Youngson, R. T. Hedlund, C. A. I. Goring, J. W. Hamaker, and W. W. Addington. 1973. Measurement and prediction of picloram disappearance rates from soil. Weed Sci. 21:549-555.

Menzer, R. E., E. L. Fontanilla, and L. P. Ditman. 1970. Degradation of disulfoton and phorate in soil influence by environmental factors and soil type. Bull. Environ. Contamin. Toxicol. 5:1-5.

Menges, R. M. and S. Tamez. 1974. Movement and persistence of bensulide and trifluralin in irrigated soil. Weed Sci. 22:67-71.

Merkle, M. G., R. W. Bovey, and F. S. Davis. 1976. Factors affecting the persistence of picloram in soil. Agron. J. 59:413-415.

Messersmith, C. G., O. C. Burnside, and T. L. Lavy. 1971. Biological and non-biological dissipation of trifluralin from soil. Weed Sci. 19: 288-290.

Miller, C. H., T. J. Monaco, and T. J. Sheet. 1976. Studies of nitralin residues in soils. Weed Sci. 24:288-291.

Mingelgrin, U. and B. Yaron. 1974. The effect of calcium salts on the degradation of parathion in sand and soil. Soil Sci. Soc. Amer. Proc. 38:914-917.

Moshier, L. T. and D. Penner. 1978. Factor influencing microbial degradation of $^{14}CO_2$ in soil. Weed Sci. 26:686-691.

Moyer, J. R., R. J. Hance, and C. E. McKone. 1972. The effect of adsorption of adsorbents on the rate of degradation of herbicides incubated with soil. Soil. Biol. Biochem. 4:307-311.

Munnecke, D. M. and D. P. H. Hsieh. 1974. Microbial decontamination of parathion and p-nitrophenol in aqueous media. Appl. Microbiol. 28: 212-217.

Namdeo, K. N. 1972. Persistence of dalapon in grassland soil. Plant Soil 31:445-448.

Nash, R. G. and E. A. Woolson. 1967. Persistence of chlorinated hydrocarbon insecticides in soils. Science 157:924-927.

Normura, N. S. and H. W. Hilton. 1977. The adsorption and degradation of glyphosate in five Hawaiian sugar cane soils. Weed Res. 17:113-121.

Obien, S. R. and R. E. Green. 1969. Degradation of atrazine in four Hawaiian soils. Weed Sci. 17:509-514.

Ou, L.-T., J. M. Davidson, and D. F. Rothwell. 1978. Response of soil microflora to high 2,4-D applications. Soil Biol. Biochem. 10:443-445.

Ou, L.-T., D. F. Rothwell, W. B. Wheeler, and J. M. Davidson. 1978. The effect of high 2,4-D concentrations on degradation and carbon dioxide evolution in soils. J. Environ. Quality 7:241-246.

Ou, L.-T. and H. C. Sikka. 1977. Extensive degradation of silvex by synergistic action of aquatic microorganisms. J. Agr. Food Chem. 25: 1336-1339.

Parr, J. F. and S. Smith. 1973. Degradation of trifluralin under laboratory conditions and soil anaerobiosis. Soil Sci. 115:55-63.

Probst. G. W., T. Golab, R. J. Herberg, F. J. Holzer, S. J. Parka, C. V. D. Shans, and J. B. Tepe. 1967. Fate of trifluralin in soils and plants. J. Agr. Food Chem. 15:592-599.

Radosevich, S. R. and W. L. Winterlin. 1977. Persistence of 2,4-D and 2,4,5-T in chaparral vegetation and soil. Weed Sci. 25:423-425.

Rajaram, K. P. and N. Sethunathan. 1975. Effect of organic sources as the degradation of parathion in flooded alluvial soil. Soil Sci. 119:296-300.

Roadhouse, F. E. B. and L. A. Birk. 1961. Penetration of and persistence in soil of the herbicide 2-chloro-4,6-bis(ethylamino)-s-trazine (simazine). Can. J. Plant Sci. 41:252-259.

Rueppel, M. L., B. B. Brightwell, J. Schaefer, and J. T. Marvel. 1977. Metabolism and degradation of glyphosate in soil and water. J. Agr. Food Chem. 25:517-526.

Sacher, R. M. G., G. F. Ludvik, and J. M. Deming. 1971. Bioactivity and persistence of some parathion formulations in soil. J. Econ. Entomol. 65:329-332.

Saltzman, S., U. Mingelgrin, and B. Yaron. 1976. Role of water in the hydrolysis of parathion and methylparathion on kaolinite. J. Agr. Food Chem. 24:739-743.

Sanborn, J. R., B. M. Francis, and R. L. Metcalf. 1976. The degradation of selected pesticides in soil: A review of the published literature. USEPA.

Savage, K. E. 1973. Nitralin and trifluralin persistence in soil. Weed Sci. 21:285-288.

Savage, K.E. and W. L. Barrentine. 1969. Trifluralin persistence as affected by depth of soil incorporation. Weed Sci. 17:349-352.

Schulz, K. R. and E. P. Lichtenstein. 1971. Field studies on the persistence and movement of dyfonate in soil. J. Econ. Entomol. 64:283-287.

Scifres, D. J. and T. J. Allen. 1973. Dissipation of dicamba from grassland soils of Texas. Weed Sci. 21:393-396.

Sethunathan, N. 1973. Degradation of parathion in flooded acid soils. J. Agr. Food Chem. 21:602-604.

Sethunathan, N. 1973. Microbial degradation of insecticides in flooded soil and in anaerobic cultures. Residue Rev. 47:143-165.

Sethunathan, N. 1973. Organic matter and parathion degradation in flooded soil. Soil Biol. Bichem. 5:641-644.

Sethunathan, N. and I. C. MacRae. 1969. Persistence and biodegradation of diazinon in submerged soils. J. Agr. Food Chem. 17:221-225.

Sethunathan, N. and T. Yoshida. 1969. Fate of diazinon in submerged soil accumulation of hydrolysis product. J. Agr. Food Chem. 17: 1192-1195.

Sethunathan, N. and Y. Yoshida. 1973. Parathion degradation in submerged rice soils in the Philippines. J. Agr. Food Chem. 21:504-506.

Siddaramappa, N., K. P. Rajaram, and N. Sethunathan. 1973. Degradation of parathion by bacteria isolated from flooded soil. Appl. Microbiol. 26:846-849.

Skipper, H. D. and V. V. Volk. 1972. Biological and chemical degradation of atrazine in three Oregon soils. Weed Sci. 20:346-347.

Sikka, H. C. and D. E. Davis. 1966. Dissipation of atrazine from soil by corn, sorghum and Johnson grass. Weeds 14:289-293.

Sirons, G. J., R. Frank and R. M. Dell. 1977. Picloram residues in sprayed MacDonald-Cartier freeway right-of-way. Bull. Environ. Contamin. Toxicol. 18:526-533.

Smith, A. E. 1972. Persistence of trifluralin in small field plots as analysis by a rapid gas chromatographic method. J. Agr. Food Chem. 20:829-831.

Smith, A. E. 1973. Degradation of dicamba in prairie soils. Weed Res. 13:373-378.

Smith, A. E. 1974. Breakdown of the herbicide dicamba and its degradation product 3,6-dichlorosalicyclic acid in prairie soils. J. Agr. Food Chem. 22:601-605.

Smith, A. E. 1974. Degradation of trichloroacetic acid in Saskatchewan soils. Soil Biol. Biochem. 5:201-212.

Smith, A. E. and D. R. Cullimore. 1975. Microbiological degradation of the herbicide dicamba in moist soils at different temperatures. Weed Res. 15:59-63.

Smith, A. E. and G. S. Edmond. 1975. Persistence of linuron in Saskatchewan soils. Can. J. Soil Sci. 55:145-148.

Smith, A. E. and A. Walker. 1977. A quantitative study of asulam persistence in soil. Pest. Sci. 8:449-456.

Spencer, W. F., M. M. Cliath, D. R. Davis, R. C. Spear, and W. J. Pependorf. 1975. Persistence of parathion and its oxidation to paraoxon on the soil surface as related to worker reentry into treated crops. Bull. Environ. Contamin. Toxicol. 14:265-272.

Sprankle, P., W. F. Meggitt, and D. Penner. 1975. Adsorption, mobility, and microbial degradation of glyphosate in the soil. Weed Sci. 23: 229-234.

Stewart, D. K. R. and D. Chisholm. 1971. Long-term persistence of BHC, DDT, and chordane in a sandy loam soil. Can. J. Soil Sci. 51:379-383.

Stewart, D. K. R. and S. O. Gaul. 1977. Persistence of 2,4-D and 2,4,5-T and dicamba in a Dykeland soil. Bull. Environ. Contamin. Toxicol. 18:210-218.

Suett, D. L. 1975. Persistence and degradation of chlorfenvinphos, chlomephos, disulfoton, phorate and pirimiphos-ethyl following spring and late-summer soil application. Pest. Sci. 6:385-393.

Suzuki, M., Y. Yamato, and T. Watanabe. 1977. Residue in soil, organochlorine insecticide residues in field soils of the Kita Kyusha district--Japan 1970-74. Pest. Monitoring J. 11:88-93.

Tafuri, F., M. Businelli, L. Scarponi, and C. Marucchini. 1977. Dieldrin and movement of AG Chlordane in soil and its residue in alfalfa. J. Agr. Food Chem. 25:353-358.

Talekar, N. S., L.-T. Sun, E.-M. Lee, and J.-S. Chen. 1977. Persistence of some insecticides in subtropical soil. J. Agr. Food Chem. 25: 348-352.

Tu, C. M. and W. B. Bollen. 1968. Interaction between paraquat and microbes in soils. Weed Res. 8:38-45.

Usorol, N. J. and R. J. Hance. 1974. The effect of temperature and water contents on the rate of decomposition of the herbicide linuron. Weed Sci. 16:19-21.

Venkateswarlu, K., T. K. Siddarame Gowda, and N. Sethunathan. 1977. Persistence and biodegradation of carbofuran in flooded soil. J. Agr. Food Chem. 25:533-536.

Voerman, S. and A. F. H. Besemer. 1975. Persistence of dieldrin, lindane, and DDT in a light sandy soil and their uptake by grass. Bull. Environ. Contamin. Toxicol. 13:501-505.

Walker, A. 1974. A simulation model for prediction of herbicide persistence. J. Environ. Quality 3:396-401.

Walker, A. 1976a. Simulation of herbicide persistence in soil. I. Simazine and prometryne. Pest. Sci. 7:41-49.

Walker. A. 1976b. Simulation of herbicide persistence in soil. II. Simazine and linuron in long-term experiments. Pest. Sci. 7:50-58.

Walker, A. 1978a. The degradation of methazole in soil. I. Effects of soil type, soil temperature, and soil moisture content. Pest. Sci. 9:326-332.

Walker, A. 1978b. Simulation of the persistence of eight soil-applied herbicides. Weed Res. 18:305-313.

Walker, W. W. 1976. Chemical and microbiological degradation of malathion and parathion in an estuarine environment. J. Environ. Quality 5: 210-215.

Walker, W. W. and B. J. Stojanovic. 1973. Microbial versus chemical degradation of malathion in soil. J. Environ. Quality 2:229-232.

Ware, G. W., B. Estesen, W. C. Kronland, and W. B. Cahill. 1977. DDT volatilization from desert and cultivated soils. Bull. Environ. Contamin. Toxicol. 17:317-322.

Watanabe, I. 1977. Pentachlorophenol-decomposing and PCP-tolerant bacteria in field soil treated with PCP. Soil Biol. Biochem. 9:99-103.

Watanabe, I. 1978. Pentachlorophenol (PCP) decomposing activity of field soils treated annually with PCP. Soil Biol. Biochem. 10:71-75.

Wheeler, W.B., C. D. Stratton, R. R. Twilley, L.-T. Ou, D. A. Carlson, and J. M. Davidson. 1979. Trifluralin degradation and binding in soil. J. Agr. Food Chem. 27:702-706.

Wilkinson, A. T. S. and D. G. Finlayson. 1964. Toxic residues in soil 9 years after treatment with aldrin and heptachlor. Science Feb. 14, 681-682.

Willis, G. H., J. F. Parr, S. Smith, and B. R. Carrol. 1972. Volatilization of dildrin from fallow soil as affected by different soil water regimes. J. Environ. Quality 1:193-196.

Wilson, R. G., Jr. and H. H. Cheng. 1976. Breakdown and movement of 2,4-D in the soil under field conditions. Weed Sci. 24:461-466.

Wilson, R. G., Jr. and H. H. Cheng. 1978. Fate of 2,4-D in a Naff silt loam soil. J. Environ. Quality 7:281-286.

Wilson, D. M. and P. C. Olaffs. 1973. Persistence and movement of α- and γ- chlordane in soil following treatment with high purity chlordane (velsical HCS-3260). Can. J. Soil Sci. 53:465-472.

Wolf, D. C. and J. P. Partin. 1974. Microbial degradation of 2-carbon-^{14}bromacil and terbacil. Soil Sci. Soc. Amer. Proc. 38:921-925.

Yaron, B. 1975. Chemical conversion of parathion on soil surfaces. Soil Sci. Soc. Amer. Proc. 39:639-642.

Yoshida, T. and T. F. Castro. 1975. Degradation of 2,4-D, 2,4,5-T, and picloram in two Philippines soils. Soil Sci. Plant Nutr. 21:397-404.

Zimdahl, R. L. and S. M. Gwynn. 1977. Soil degradation of three dinitroanilines. Weed Sci. 25:247-251.

Zimdahl, R. L., V. H. Freed, M. L. Montgomery, and W. R. Furtick. 1970. The degradation of triazine and uracil herbicides in soil. Weed Res. 10:18-26.

Ambrosi, D., P. C. Kearney, and J. A. Macchia. 1977. Persistence and metabolism of phosalone in soil. Jour. Agric. Food Chem. 25:342-347.

Bartha, R. 1971. Fate of herbicide-derived chloroanilines in soil. Jour. Agric. Food Chem. 19:385-387.

Chiska, H., and P. C. Kearney. 1970. Metabolism of propanil in soils. Jour. Agric. Food Chem. 18:854-858.

Flashinski, S. J., and E. P. Lichtenstein. 1974. Degradation of dybonate in soil incubated with *Rhzopus arrhizus*. Can. Jour. Microb. 20:871-875.

Hsu, T. S., and R. Bartha. 1976. Hydrolyzable and non-hydrolyzable 3,4-dichloroaniline-humus complexes and their respective rates of biodegradation. Jour. Agric. Food Chem. 24:118-122.

SECTION 6

PARTITIONING OF INORGANIC PHOSPHATE IN SOIL-WATER SYSTEMS

V. E. Berkheiser, J. J. Street, P. S. C. Rao, and T. L. Yuan

Phosphorus has been implicated as a primary factor contributing to eutrophication of surface water supplies (Ohle,1953; Mackenthun, 1965; Stewart and Rohlick, 1967; Vollenweider, 1968; Lee, 1970). The contribution of soil-applied phosphorus to runoff from watersheds in agricultural areas needs to be elucidated. A prerequisite to understanding the role of P-fertilizer in runoff is an assessment of the interaction of phosphorus and soil constituents (e.g. clay minerals, metal oxides, etc.). The nature of phosphorus-soil reactions is complex, as evidenced by the large number of investigative papers in the literature (Beckett and White, 1964; Ozanne and Shaw, 1967; Kafkafi et al., 1967; Fox and Kamprath, 1970; Gunary, 1970). The complex nature of P reactions with soils and soil constituents have been extensively investigated and will be discussed in the following sections of this report.

Since soil is a dynamic chemical and biological system in a constant state of flux and disequilibrium, interpretation of research in closed artificial systems should be made with caution. It is hoped that research conducted by this group of investigators can add to the understandings thus far established. The primary research objectives, to be elaborated on later, are to quantitatively and qualitatively assess the processes responsible for partitioning of inorganic phosphorus between the solution phase and the solid phase of soils. The reaction of soluble phosphorus with soils must begin with an assessment of the chemical forms of P involved, the nature of the soil constituents, and the kinetics and reversibility of the reaction.

Soil phosphorus is generally divided into two broad categories: inorganic P, that associated with the soil mineral particles; and organic P, that which forms an integral part of the soil organic matter fraction. The organic-P fraction, which may constitute 20 to 80 percent of the total soil phosphorus, is inert in its organic form. It is only after mineralization that it becomes involved in the chemical reactions discussed in this review.

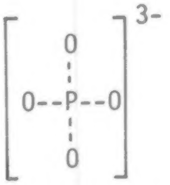
The nature of P retention by soils has been postulated to include precipitation of discrete P minerals, surface adsorption on minerals, microbial immobilization, plant uptake, and precipitation of mixed P solid phases (Hsu, 1964). The importance of any one or combination of these mechanisms is dependent on a host of variables that is often difficult to evaluate. This report will discuss some of the literature related to these processes involving soil phosphorus.

During the past 10 to 15 years there has been a tremendous increase in the amount of research dealing with the chemistry of soil phosphorus. This rapid growth in conjunction with the wide range of disciplines conducting the research has generated some confusing nomenclature with regard to the forms of phosphorus occurring in soils. This confusion in terminology reflects the complexity of soil phosphorus. The inorganic soil phosphorus forms generally encountered in the literature include the following: soil solution inorganic phosphate, fertilizer phosphate, adsorbed phosphate (rapidly reacting), adsorbed phosphate (slowly reacting), and discrete crystalline phosphates. Other terminology that may be grouped under the aforementioned phases include: occluded P, non-occluded P, isotopically exchangeable P, resin-extractable P, "sorbed P", precipitated P, exchangeable soil P, "surface phosphorus", labile, and non-labile P.

The soil solution phase mediates a multitude of phosphorus transformation reactions in soils. The inorganic phosphorus in the soil solution takes part in many complex equilibria; some of these are within the liquid phase only (homogeneous equilibria) and others occur between the solid and aqueous phase (heterogeneous equilibria). The overall equilibrium, expressed as $P_{solid} \leftrightarrows P_{solution}$ is heavily biased by the reaction to the left and soil phosphorus can be classified as "sparingly soluble."

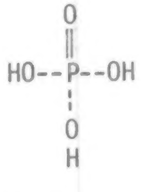
Phosphorus in Soil Solution

Phosphorus occurs in nature almost exclusively as phosphate, the fully oxidized state, with formal oxidation number V and coordination number 4. Phosphate occurs in all known minerals as orthophosphate, the ionic form being represented as



$$\left[\begin{array}{c} O \\ \vdots \\ O\text{--}P\text{--}O \\ \vdots \\ O \end{array}\right]^{3-} \qquad [6\text{-}1]$$

or as $[PO_4]^{3-}$. The distribution of the several acid and base species of orthophosphates in solution is governed by pH. Information on the pH-dependent distribution of the different species is required in interpreting the solubility behavior, complex formation and sorption processes of phosphorus in the soil-water system. Orthophosphoric acid dissociates stepwise in aqueous systems releasing a total of three protons as pH increases.



$$\begin{array}{c} O \\ \| \\ HO\text{--}P\text{--}OH \\ \vdots \\ O \\ H \end{array} \qquad [6\text{-}2]$$

Orthophosphoric Acid

	log k^0	
$H_3PO_4 \longleftrightarrow H^+ + H_2PO_4^-$	-2.12	[6-3]
$H_2PO_4^- \longleftrightarrow H^+ + HPO_4^{2-}$	-7.22	[6-4]
$HPO_4^{2-} \longleftrightarrow H^+ + PO_4^{3-}$	-12.33	[6-5]

Thus it can be seen from equations 6-3 through 6-5 that a change in the pH results in a subsequent change in the ratio of the different orthophosphate species. If the solution pH is 2.12 the ratio of $H_3PO_4/H_2PO_4^-$ is unity and solution pH's of 7.22 and 12.33, respectively, result in $H_2PO_4^-/HPO_4^{2-}$ and HPO_4^{2-}/PO^{3-} ratios being unity. Thus in interpreting the chemistry of phosphorus in the soil-water system it is pertinent that notice be given to the pH of the system. A plot showing the orthophosphate species as the logarithm of the mole fraction of the total P in solution is given as a function of pH in Figure 6-1. As can be readily seen from Figure 6-1, the $H_2PO_4^-$ and HPO_4^{2} ions are the predominanty species that can be expected to take part in phosphate sorption reactions in the soil solution of most agricultural soils in the pH range of 4.0 to 8.5.

The concentration of phosphorus in the soil solution is of the order of 1 to 0.1 μg P/ml. It varies with the properties of both the solid and the aqueous phases of the soil and also with the solid/solution ratio. The chemical species of solution phosphorus are a function of the reactions of protonation and soluble complex ion formation. These species include H_3PO_4, $H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}, and the soluble complexes of these ions. The degree of complexation and the predominance of a particular phosphoric acid species can be calculated from a knowledge of the pH, the complexing cation concentration, and the cation-phosphate complex stability constant, and the ionic strength of the medium (Sillen and Martell, 1964). The ionic species $H_2PO_4^{2-}$ are the predominant phosphoric acid dissociation products in solution in most soils (pH range 4.0-8.5). Since the soil solution will contain several kinds of metallic cations (i.e., Ca^{2+}, Mg^{2+}, K^+, Fe^{3+}, Al^{3+}, etc.) capable of forming complexes with $H_2PO_4^-$ and HPO_4^{2+}, a part of the solution phosphorus will exist as soluble metallic-phosphate complexes (i.e., $CaH_2PO_4^+$, $CaHPO_4^\circ$, $FeH_2PO_4^{2+}$, etc.). In some cases the degree of complexation of solution phosphorus may be a significant part of the total soil solution phosphorus (Larsen, 1965, 1966a; Weir and Soper, 1963; Taylor and Gurney, 1962a). The chemical speciation of soil solution phosphorus is an important part of the chemical reactions that govern the distribution of soil applied P between the solution phase and the solid phase.

Discrete Crystalline Phosphates

Based on the "Solubility Product" principle it has been postulated that Fe, Al, and Ca may precipitate out soil solution phosphorus (Kittrick and Jackson, 1957; Hemwell, 1957; Charkravarti and Talibudeen, 1962; Shipp and Matelski, 1960). However, the general occurrence of discrete Fe and Al phosphates as factors controlling soluble P levels in soils seems doubtful on the basis of ion product data presented by Bache (1964) and the experimental observations of Hsu (1964). It is not surprising to find conflicting published

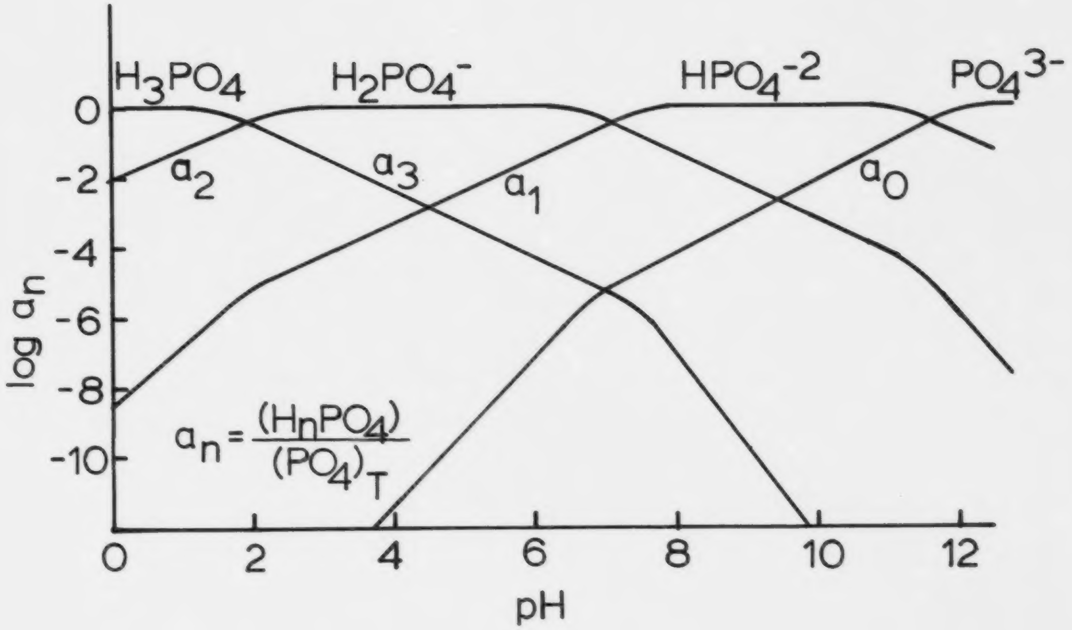


Figure 6-1. Inorganic orthophosphate speciation in aqueous solutions as a function of pH.

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

research concerning the presence of discrete solid phase phosphorus compounds based on the solubility product values published for "pure" well-defined crystalline compounds. The lack of agreement between phosphorus concentration in the soil solution and the solubility of a pure crystalline compound does not exclude the presence of such a compound. The problem of incongruent dissolution and complex formation, impurities, and degree of crystallinity can all contribute to the disparity between calculated and observed solubility products (Bjerrium, 1949; Greenwald, 1942; Ericsson, 1949; Taylor and Gurney, 1962a; Raupach, 1963).

The use of solubility diagrams to evaluate the upper limits of P soluble in soils is a valid and useful aid in understanding phosphate reactions in soils (Stumm and Morgan, 1970; Lindsay and Vlek, 1977; Griffin and Jurinak, 1974). The solubility diagram presented in Figure 6-2 was adapted from stumm and Leckie (1971) and assumes a Ca^{2+} activity of 10^{-3}M, F^- activity controlled by CaF_2, and an Al^{3+} and Fe^{3+} activity controlled by $\bar{A}l(OH)_3$ and $Fe(OH)_3$, respectively. As evident in Figure 6-2, Al^{3+} and Fe^{3+} control P solubility at low pH values and Ca^{2+} controls the P level under alkaline conditions. The preceding discussion on discrete P minerals is by no means conclusive and there exist many other possible P minerals. Sillen and Martell (1964) have listed some relevant sparingly soluble phosphorus salts of magnesium, calcium, aluminum, iron, and potassium, while Nriagu (1976) has recently evaluated several geologically important phyochate minerals.

Although Hsu (1976) discussed the terms precipitation and adsorption, it is difficult to distinguish between the initial reaction of precipitation and adsorption. As a result, these two phenomenon are often grouped together as "sorption." There is probably a continuum in terms of reaction rates between the various adsorbed and crystalline phosphates. Thus, their distinction on a kinetic basis is difficult (Larsen, 1967) and must be largely arbitrary except under special conditions such as "microsites" around fertilizer granules.

The presence of discrete solid phases is probably a more important mechanism for controlling soluble P levels in the vicinity of phosphate fertilizer particles than in the bulk soil. The presence of Fe and Al phosphates has been reported as temporary soil-fertilizer reaction products around fertilizer granules (Lindsay and Stephenson, 1959; Huffman, 1969). The presence of discrete phosphorus solid phases, whether around a fertilizer particle or on the surface of a P-enriched site of some other mineral, is a feasible and likely mechanism for P retention in soil.

It has been postulated that phosphate adsorption (chemical) and precipitation are basically the same mechanism, both being a fundemently attraction between Al (or Fe) and phosphate (Mattson et al., 1951; Kittrick and Jackson, 1957; Hsu and Rennie, 1962). Hsu (1964) has suggested that phosphate adsorption is a special case of precipitation in which Al or Fe remains as the constituent atom of the corresponding metal hydroxide or oxide; however, he also elaborates on the practical point that conceptually there are some basic differences in the two processes.

Because of the large volume of literature and apparent contradictory evaluation of the magnitude of phosphate sorption-desorption by soils, an attempt was made here to determine a universal partition function from the literature data. Phosphorus sorption-desorption and transformations in the current version of the Agricultural Runoff Management (ARM) model (Donigan et al., 1977) can be depicted as follows:

$$\begin{tikzcd}
 & \text{PLANT PHOSPHATE} & \\
\text{ADSORBED PHOSPHATE} \arrow[r, shift left, "k_{AS}"] & \text{SOLUTION PHOSPHATE} \arrow[l, shift left, "k_{SA}"] \arrow[u, "k_{PL}"'] \arrow[r, shift left, "k_{IM}"] & \text{ORGANIC PHOSPHATE} \arrow[l, shift left, "k_{M}"]
\end{tikzcd}$$

This model assumes that all reaction rates are first-order in phosphate concentration in the corresponding phases and that the forms of phosphate can be described as shown above. The present discussion is restricted to the relationship between the inorganic phosphate in sorbed and solid phases and that in solution phase.

This report represents the first effort at a quantitative review of phosphate sorption literature. In this review, discussions of sorption mechanisms as well as kinetic and equilibrium models are brought to focus in quantifying and predicting the relation between solution and solid phase concentrations of phosphate in soil-water systems. Attempts at correlating Langmuir sorption parameters with selected soil chemical properties will be discussed as a simple means of predicting the partition function for other soils given only the chemical properties.

MODELS FOR EQUILIBRIUM SORPTION-DESORPTION OF PHOSPHORUS

Three equations, developed for gas-solid systems, have been adapted for use in modelling the sorption of phosphate ions on charged surfaces. These are the Langmuir, Freundlich, and Temkin equations. Each equation can be developed from statistical mechanical considerations of gas adsorption by clean surfaces. Table 6-1 lists the assumptions underlying the derivation of each equation. The added restriction of electroneutrality $\Sigma z_i n_i = 0$, where n_i is the number of ions or ionized sites each with a charge of z_i, has made applications of these equations to electrolyte systems somewhat empirical. When applied to natural systems of a composite nature such as soils and sediments, these equations have been found to describe the adsorption of phosphate less than satisfactorily over a wide range of phosphate concentrations (0-500 μg P/ml).

By far the most widely used model is the Langmuir equation which was originally applied to phosphate adsorption on soils by Olsen and Watanabe (1957). The simple Langmuir equation is written,

$$\frac{C}{S} = \frac{1}{kS_{max}} + \frac{C}{S_{max}} \qquad [6\text{-}6]$$

where, C = solution concentration of phosphate (μg P/ml), S = adsorbed

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

Table 6-1. Assumptions underlying the derivations of adsorption equations.

Equation	Assumptions and general methods for deriving equations
Langmuir	Localized monolayer adsorption (adsorbate nonmobile) Heat of adsorption Q constant over entire monolayer No lateral interactions of adsorbate molecules S_{max} and k are independent of temperature Rate of desorption set equal to rate of adsorption
Freundlich	Localized monolayer adsorption No lateral interactions of adsorbate molecules Exponential frequency distribution f(Q) of adsorption sites such that $f(Q) = \alpha e^{-Q/nRT}$ f(Q) combined with the Langmuir equation give the Freundlich
Temkin	Sites vary in Q according to $Q = Q_o (1 - \alpha\Theta)$ where Θ is the fractional surface coverage Q substituted into Langmuir equation

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin-1)
(4-76)

phosphate at concentration c (μg P/g soil), S_{max} = adsorption maximum at which phosphate forms a monolayer on the solid surface (μg P/g soil), and k = a constant related to the bonding energy of the phosphate on the solid surface (ml/μg P).

Conceptually, Eq. [6-6] can be used to measure the amount of phosphate that a soil can adsorb. The equation has been utilized in describing the fertility status of soil phosphate (Olsen and Watanabe, 1957; Fox and Kamprath, 1970). Since the parameter k is related to the bonding energy of phosphate to the soil, it has been regarded as an "intensity" factor by several workers. The magnitude has been empirically and erroneously interpreted as the "bonding" energy of the phosphate to the soil. However, since k is related to the energy of adsorption, it may find usefulness in describing partitioning of phosphate between solid and solution phases. The S_{max} term has been related to "quantity" factors and as measure of the capacity of a soil to retain phosphate. Both terms allow qualitative measures of phosphate availability to agricultural crops.

The quantitative measurement of phosphate partitioning between solution and solid phases remains largely undescribed. Causes of this deficiency rest largely in the lack of detailed knowledge of the structure and composition of the solid surface with which the phosphate reacts. Adsorption potential energies of surfaces in soil systems are not usually uniform in distribution. Each mineral and type of organic matter can be expected to adsorb phosphate with different adsorption energies. Surface areas contributing to each type of adsorbent are not likely to be equal.

Because of this non-uniformity of site populations, Syers et al. (1973) used a curve splitting technique, similar to the method developed by Shapiro and Fried (1959), to describe phosphate sorption by Brazilian soils. The Langmuir equation, originally proposed to describe sites of more than one population (Langmuir, 1918), was written

$$s = \frac{k' S'_{max} c}{1 + k'c} + \frac{k'' S''_{max} c}{1 + k''c} + \ldots. \qquad [6\text{-}7]$$

where the symbols are as defined for Eq. [6-6]; primes refer to site populations 1 and 2, respectively. In a similar manner, Holford et al. (1974) adapted the multi-site Langmuir equation to phosphate adsorption. Their equation was written the same as Eq. [6-7].

Holford et al. (1974) evaluated both the single-surface and two-surface equations and found correlation coefficients of 0.99 for the single-surface model (Eq. 6-6) and 1.00 for the two-surface expression (Eq. 6-7). Using regression coefficients for k and S_{max}, they found that Eq. [6-6] underestimates phosphate adsorption at low (0-2 μg P/ml) and high (> 12 μg P/ml-for slightly adsorbing soils) equilibrium phosphate concentrations. Both of these studies concluded that two populations of sites exist in soils for adsorption of phosphate. The strongly adsorbing population was characterized by high k values which were two orders of magnitude larger than those for the more weakly adsorbing population.

TYPING GUIDE SHEET

Several empirical modifications of the Langmuir equation were introduced by Gunary (1970). Four equations were fitted to phosphate adsorption data of 24 soils by least-squares regression analysis and were written:

$$c/y = a + bc \tag{6-8a}$$

$$cy = a_1 + b_1c + d_1c^2 \tag{6-8b}$$

$$c/y = a_2 + b_2c + d_2 \quad c \tag{6-8c}$$

$$\log c/y = a_3 + b_3 \log c \tag{6-8d}$$

Eq. [6-8a] is seen to be in the form of the Langmuir equation and Eqs [6-8b] and [6-8c] are modifications thereof. Eq. [6-8d] is a modification of the Freundlich equation. From their statistical analysis, they concluded that Eq. [6-8c] described the data better than the Langmuir equation. Eq. [6-8c] always gave S_{max} values that were 1.5 to 2 times that obtained from the Langmuir expression. Unfortunately, no theoretical foundation for Eqs. [6-8a-8d) was given and thus makes insight into the causes of phosphate adsorption difficult.

The Freundlich adsorption equation was first applied to phosphate adsorption by Low and Black (1950). In their study of the correlation of phosphate adsorption with release of Al and Si from kaolinite, the equation used to express adsorption of phosphate was

$$s = kC^{1/n} \tag{6-9}$$

where, s = phosphate adsorbed (μg P/g kaolinite), k = a constant (not necessarily equal to the Langmuir k), c = equilibrium concentration of phosphate (μg P/ml), and 1/n = constant. The authors reported values of k = 0.562 and 1/n = 0.388 for their kaolinite sample.

Fitter and Sutton (1975) used a modified Freundlich equation

$$s + a = bC^k \tag{6-10}$$

where, s = phosphate adsorbed in the experiment (μg P/g soil), a = constant which corrects for phosphate already present in the soil (μg P/g soil), C = equilibrium concentration of phosphate (μg P/ml), and b, k = constants. This equation appeared to describe phosphate sorption data on 29 soils from England. The value of a was determined by multiplying resin-extractable phosphate by a factor of 2.

Bache and Williams (1971) have used the Temkin for describing phosphorus adsorption by soils. The Temkin equation is stated as:

$$\frac{S}{S_{max}} = \frac{RT}{b} \ln (Ac) \tag{6-11}$$

where, R = gas constant (cal mole^{-1} deg^{-1}), T = absolute temperature (°K), A,b are constants, and other symbols are as defined for Eq. [6-6]. The

EPA-287 (Cin.)
(4-76)

phosphorus adsorption isotherms plotted according to the Temkin equation were reported to deviate from linearity in a manner similar to that from Langmuir plots. Bache and Williams (1971) proposed a sorption index, dS/d ln C, obtained from the slopes of a plot of S versus ln C. Comparison of this sorption index with other indices gave significant correlations in most cases. For the soils tested by Backe ahd Williams (1971), correlation coefficients of 0.99 and 0.28 were obtained, respectively, for regression of sorption index with the Langmuir constant S_{max} and k.

The above expressions are all denied for gas adsorption by solids and as such do not explicitly contain terms which consider ionic interactions. A model of ionic adsorption onto variable change mineral surface was derived by Bowden et al. (1973, 1977). Their derivation was based on the Stern model of the electrical double layer which is present at the interface between electrolyte solution and a solid surface composed of ionizable species. The model unlike others, accounts for specific adsorption of ionic species from solution. This specific adsorption changes the potential Ψ_d (at the plane between the Stern layer and the diffuse layer) to a different extent than changes in Ψ_d imposed by changes in concentration of the indifferent electrolyte.

The model involves five equations in five unknowns and predicted phosphate adsorption by goethite over a range of pH's from pH 2 to pH 11. The applicable set of equations are written:

$$\sigma_i = \frac{N_i \Sigma z_i K_i C_i \exp(--z_i F\Psi_d/RT)}{1 + \Sigma K_i C_i \exp(--z_i F\Psi_d/RT}\,, \qquad [6\text{-}12]$$

$$C_1 = C_{zn(11)} K_1(\alpha_H)[(\alpha_H)^2 + K_1(\alpha_H) + K_1K_2], \qquad [6\text{-}13]$$

$$\sigma_d = --1{\cdot}22 \text{ X } 10^{-10} C^{1/2} \sinh(0{\cdot}0195|z|\Psi_d) \qquad [6\text{-}14]$$

$$\sigma_s + \sigma_i + \sigma_d = 0. \qquad [6\text{-}15]$$

$$(\Psi_s--\Psi_d) = (4\pi d/\varepsilon_d)\sigma_s = \sigma_s/G, \qquad [6\text{-}16]$$

The parameters N_s, K_H, K_{OH}, and G were estimated independently from titration curves of goethite in NaCl solution [a plot of log Γ_i versus pH at low surface coverage of i gives an intercept of log $(a_i)k_i$]. They are described as follows:

N_s = surface population density of adsorption sites (moles/cm^2)

K_H, K_{OH} = binding constants of H^+ and OH^- ions on the metal oxide surface

K_i = binding constant of other adsorbing ions on the metal oxide surface

G = integral electrical capacitance of the region between the Stern layer and diffuse layer (G can be computed using plots of the change in charge of the Stern layer with the change in pH)

N_T = maximum number of ions adsorbed in the Stern layer

Z_i = charge on ion i

C_i = concentration of ion i in the bulk solution

F,R = Faraday and gas constants, respectively

α_H = activity of hydrogen ions in bulk solution

σ_d = charge density at the interface between the Stern and diffuse layers

σ_s = charge density at the interface between the solid surface and the Stern layer

Ψ_d, Ψ_s = potentials at the isopective interfaces

ε_d = permittivity of the medium in the diffuse layer.

Other models for the adsorption of gases and vapors on solids have been introduced (Adamson, 1975). Each model attempts to describe the phenomenon of adsorption from basic physical and quantum parameters. Often the models apply to clean surfaces with uniform surface potentials quite unlike those found in soil systems. Recently. models have appeared which include surface heterogeneity in the treatment. In addition a promising area of study would appear to be the inclusion of the additional condition of electroneutrality in gas-solid adsorption models.

The models described above, explain the experimental data satisfactorily in most cases for a given isotherm or solid phase. In nearly all cases, statistical fits of experimental data showed that the models predicted phosphate adsorption with correlation coefficients of 0.9 or higher. Because of assumptions made in model derivations, the "goodness-of-fit" does not necessarily correspond to "correctness" of the model when applied to other solids. Such solids may differ in bonding structure, porosity, crystallinity, and content of impurities. As a consequence of these variables, correlations of soil chemical and/or physical properties with sorption parameters obtained using the adsorption models would not be straightforward. The degree to which soil properties are correlated with sorption parameters has been tested and is the subject of the next section of this report. If the models are taken to describe phosphate adsorption adequately, the lack of correlation of model parameters with soil properties likely results from inaccurate characterization of the adsorption mechanisms and poor description of sites.

CORRELATIONS OF PHOSPHATE SORPTION PARAMETERS AND SELECTED SOIL PROPERTIES

Much effort has been directed toward a mathematical formulation which relates soil chemical and physical properties with phosphate sorption and release. The requirement for a model which predicts the amount of phosphate released from watersheds provides the need for such a function. The appropriate partition function will have several characteristics:

1) It will apply to a wide variety of soil conditions and compositions,

2) Predictions of phosphate partitioning will have a minimum amount of error; e.g., less than or equal to a factor of two,

3) The function will be mathematically tractable to expedite computations, and

4) The function will be based upon soil properties which are easily measured in the laboratory.

In order to develop such a partition function, two approaches are evident. First, the soil can be divided into its particular set of organic and inorganic constituents and phosphate sorption quantified on each fraction. In this way, a universal partition function based on a measurable set of soil properties could, presumably, be derived. Second, phosphate sorption-desorption can be quantitated on all individual types of soil. Statistical correlations of the sorption parameters with the soil properties would give the partition function. Both approaches appear concurrently in the literature. If, however, one type of soil constituent dominates the sorption-desorption process, it would seem worthwhile to investigate in detail the sorption processes unique to that particular constituent.

Several authors have statistically correlated soil chemical properties with phosphate sorption parameters. The soil properties have included pH, $CaCO_3$ content, particle size distribution, extractable Fe and Al (by several methods), and organic carbon content. Phosphate sorption parameters have consisted of a single-valued sorption index (phosphate adsorbed at a single level of added phosphate), constants from the Langmuir and Freundlich equations, and the Bache and Williams index. These correlation coefficients (and linear regression equations, in some cases) are presented in Appendix C, Tables C1-C9. Most emphasis has been placed on the effect of Fe and Al constituents in the soil which form relatively insoluble complexes and precipitates with phosphate. Although the influence of organic matter on phosphate adsorption has been debated, organic matter appears to effect phosphate adsorption in an indirect manner. Organically complexed Fe^{3+} and Al^{3+} are the most likely sites for adsorption on organic matter surfaces (Weir and Soper, 1963 and Syers et al., 1971).

The oxyhydroxy Fe and Al constituents of the soils which have been reported play a major role in determining the sorption of phosphorus in soils (Ryde et al., 1977a,b). Based on such reports, we have attempted to normalize the Langmuir sorption parameters with respect to extractable Fe and Al content of a wide range of soils and sediments with an intent to derive "universal" coefficients applicable to all soils. This approach is similar to that used to estimate pesticide adsorption coefficients based solely on soil organic carbon.

A literature search was performed to obtain information from as many soils as possible from which a correlation could be derived with a reasonable amount of error. Of those papers reporting sorption parameters, nearly all were based upon the Langmuir equation, though a few Freundlich constants were found. In some cases, Langmuir sorption parameters were computed from published isotherms. Langmuir parameters are tabulated in Tables C6 and C22 along with the corresponding descriptions of soils and methods in Tables C11-C21 and C23-C30, respectively. Those articles which contained chemical analyses of Fe^{3+} or Al^{3+}, in addition to sorption parameters, are summarized in Table 6-2. Overall means, standard deviations, and coefficients of variation are given in Table 6-3. For purposes of analysis, natural logarithms of the values, and parameters normalized with respect to Fe^{3+}, Al^{3+}, or $Fe^{3+} + Al^{3+}$ are also listed in Table 6-3.

The Langmuir parameter S_{max} ranges from 4,420 to 12.6 µg P/g soil with a mean of 434 µg P/g soil and a CV of 168%. Corresponding values for the Langmuir k show a range of 23.8 to 0.41 $\frac{ml}{\mu g\ P}$ with a mean of 4.8 $\frac{ml}{\mu g\ P}$ and a CV of 109. Coefficients of variation were considerably lower for logarithmic values of S_{max} and k, 25 and 101, respectively. An even greater improvement in lowering the variability of S_{max} and k values was obtained when these parameters were normalized with respect to extractable Fe and Al. The CV values for logarithms of normalized parameters were on the order of 10-20 for normalized k and 40 to 80 for normalized S_{max}.

Two important conclusions emerge from the above correlations. First, a significant relationship exists between extractable "active" Al^{3+} and Fe^{3+} in the soils tested within individual studies. The "active" Fe^{3+} and Al^{3+} appear to be more consistently extracted by a reagent containing oxalic acid (Saunders, 1965; Williams et al., 1958; Sree Ramulu et al., 1967), as an acid oxalate solution (Tamm, 1932), or as ammonium oxalate-oxalic acid solution (Schwertmann, 1964). In contrast to the oxalate methods, analyses which employ dithionite to reduce Fe^{3+} to Fe^{2+} probably extract more Fe^{3+} than is active in phosphate sorption. The interiors of iron-containing oxyhydroxide crystals and interlayers of phyllosilicates probably contribute "nonactive" Fe and Al which is not likely to participate in sorption of phosphate. In addition to differences in extractants used, inconsistancy in methods among laboratories appear to account for the large variability observed in extractable Fe and Al. This variability is not surprising since chemical methods of analysis employ several steps which vary from experimenter to experimenter. Time of reaction with the reducing agent, temperature of the reaction mixture, presence of light (in the method of Schwertmann, 1964), and pH of the buffer system are some of the experimental variables. Lack of consistency indicates a need for standardization of Fe and Al extractions when relating the data to phosphate sorption.

Second, the single point isotherm has been the most popular in determining the phosphate sorption parameter. This method has not been uniform from

TYPING GUIDE SHEET

Table 6-2. Summary of phosphate sorption parameters and soil chemical properties used in linear regression analysis.

SOIL	REF*	k, $\frac{ml}{\mu g\ P}$	S_{max} µg P/g soil	CDB Fe^{3+}	CDB Al^{3+}	Oxalate Fe^{3+}	Oxalate Al^{3+}	pH
ALLIGATOR	1	148	17.2	0.150	.	.	.	6.3
CRIDER	1	100	15.2	0.150	.	.	.	6.7
GRANADA	1	092	13.1	0.100	.	.	.	6.8
PAMBROKE	1	097	14.4	0.140	.	.	.	7.0
ZANESVILLE	1	123	12.6	0.110	.	.	.	7.0
VENAGO	2	.	847.0	0.380	0.110	.	.	4.7
HUMATAS	2	.	684.0	0.160	0.044	.	.	4.4
CATALINA	2	.	683.0	0.220	0.056	.	.	4.9
CORDZAL	2	.	468.0	0.110	0.044	.	.	4.2
EUTAW	2	.	390.0	0.200	0.078	.	.	4.7
AGAWAN	2	.	341.0	0.200	0.089	.	.	6.3
DAVIDSON	2	.	323.0	0.630	0.096	.	.	6.5
GEORGEVILLE	2	.	262.0	0.850	0.096	.	.	5.5
COTO	2	.	252.0	0.130	0.093	.	.	4.5
COOLVILLE	2	.	228.0	0.210	0.067	.	.	4.6
WANPUN	2	.	211.0	0.200	0.033	.	.	7.1
VALLERS	2	.	175.0	0.045	0.007	.	.	7.7
PUTNAM	2	.	128.0	0.210	0.033	.	.	6.0
EDINA	2	.	102.0	0.160	0.026	.	.	6.1
PORTSMOUNT	2	.	126.0	0.039	0.067	.	.	5.0
WEBSTER	2	.	83.0	0.160	0.019	.	.	6.8
CLERMONT	2	.	58.0	0.170	0.026	.	.	6.5
NACOGDOCHES	2	.	55.0	1.750	0.110	.	.	6.7
SAO GABRIEL	3	4.80	73.0	0.020	0.026	0.012	0.009	5.2
CAMBIA	3	4.70	224.0	0.100	0.067	0.032	0.040	5.1
DUROX	3	10.90	990.0	0.410	0.190	0.026	0.033	3.7
WEBSTER	4	0.44	328.0	0.270	.	.	.	6.1
IDA	4	0.41	253.0	0.130	.	.	.	8.0
SOIL1	5	13.50	1040.0	0.930	0.440	.	.	4.2
SOIL2	5	23.80	451.0	0.140	0.110	.	.	5.2
SOIL3	5	9.90	1385.0	0.380	0.190	.	.	6.2
EGMONT	6	2.02	4420.0	0.120	0.780	.	.	7.1
OKAIHAU	6	2.51	2150.0	0.790	0.120	.	.	5.0
WAIKAKAHI	6	6.33	275.0	0.100	0.081	.	.	7.7
PORIRUA	6	2.72	461.0	0.790	0.120	.	.	5.0
LM52	7	7.11	112.0	0.170	.	.	.	.
LM67	7	6.44	124.0	0.600	.	.	.	.
LM70	7	9.95	105.0	0.380	.	.	.	.
ROSELINS 1	8	1.69	287.0	0.360	0.094	0.280	0.100	6.4
BROUGHTON	8	4.89	209.0	0.380	0.094	0.120	0.100	7.3

Continued

EPA-287 (Cin.)
(4-75)

Table 6-2. (Continued).

SOIL	REF*	k, $\frac{ml}{\mu g\ P}$	S_{max} µg P/g soil	CDB		Oxalate		pH
				Fe^{3+}	Al^{3+}	Fe^{3+}	Al^{3+}	
ROSELINS 11	8	2.85	249.0	0.450	0.087	0.240	0.120	6.0
PAULDING	8	4.35	216.0	0.310	0.110	0.280	0.200	6.6
LENAWEE	8	0.80	244.0	0.580	0.170	0.290	0.130	5.4
BLOUNT	8	2.15	199.0	0.380	0.080	0.620	0.200	6.7
HOYTVILLE	8	1.49	258.0	0.290	0.080	0.190	0.150	7.1

*1 = Ballaux and Peaslee (1975); 2 = Vijayachandran and Harter (1975); 3 = Syers et al. (1973); 4 = Singh and Tabatabai (1976); 5 = Barrow (1972); 6 = Ryden and Syers (1975); 7 = Holford and Mattingly; 8 = McCallister and Logan (1978).

Table 6-3. Summary of means, standard deviations, and coefficients of variation of sorption parameters and extractable Fe and Al.

VARIABLE*	N	MEAN	STANDARD DEVIATION	C.V.
K	27	212.6	452.0	212.5
SMAX	45	434.2	728.8	167.8
FE1	45	0.3	0.3	97.1
AL1	35	0.1	0.1	122.9
FE2	10	0.2	0.1	87.1
AL2	10	0.1	0.0	61.2
PH	42	5.9	1.1	18.5
FEAL1	35	0.4	0.3	83.7
FEAL2	10	0.3	0.2	75.7
LNFEAL1	35	-1.0	0.8	-77.4
LNFEAL2	10	-1.5	1.1	-73.3
SMAX1	45	2225.6	5431.1	244.0
SMAX2	35	5385.0	5132.1	95.3
SMAX3	35	1301.5	1101.0	84.5
SMAX4	10	5825.6	11570.5	198.6
SMAX5	10	5641.8	8846.8	156.8
SMAX6	10	2779.6	5046.2	181.5
K1	27	1656.6	3552.3	214.4
K2	17	54.5	59.1	108.2
K3	17	20.9	31.2	149.2
K4	10	105.4	166.1	157.5
K5	10	111.9	178.2	159.2
K6	10	53.1	83.7	157.6
LNSMAX1	45	6.8	1.3	19.5
LNSMAX2	35	8.2	0.7	9.0
LNSMAX3	35	6.8	0.9	14.3
LNSMAX4	10	7.5	1.3	18.4
LNSMAX5	10	8.0	1.0	12.9
LNSMAX6	10	7.0	1.2	17.5
LNK1	27	3.7	2.8	76.0
LNK2	17	3.5	1.1	31.8
LNK3	17	2.2	1.2	58.4
LNK4	10	3.2	1.8	58.7
LNK5	10	3.6	1.5	41.9
LNK6	10	2.6	1.7	64.6
LNFE1	45	-1.4	0.8	-58.6
LNAL1	35	-2.5	0.8	-33.5
LNFE2	10	-2.0	1.2	-61.4
LNAL2	10	-2.5	0.9	-38.7
LNSMAX	45	5.3	1.3	24.5
LNK	27	2.3	2.4	105.4

*See Table 6-4 for explanation of symbols used for variables.

study to study. Saunders (1965) used a modification of the method developed by Piper (1942). His modified method presumably fully saturates phosphate sorption sites by shaking 24 hours in a pH 4.6 NaOAc-HOAc buffer containing 0.032 M KH_2PO_4 (500 µg P/100 g air-dried soil). Williams et al. (1958) used Piper's method directly which saturates the soil with phosphate in 1 N $(NH_4)_3PO_4$ buffered at pH 4.0. Excess phosphate was removed with alcohol, and the adsorbed phosphate was extracted with 0.125 N NaOH. In contract to adsoption at pH 4, Williams et al. (1958) also measured adsorption at pH 2.6 by shaking the soil in a solution of 2.5 volume % HOAc and KH_2PO_4 equivalent to 67 µg P/100 g soil. P adsorbed was computed as P added + acetate extractable P (on untreated soil) - P remaining in solution. In another study, phosphate retention was measured on California soils by adding ^{32}P-labelled monocalcium phosphate to the soil (Sree Ramulu et al., 1967). Phosphate level was 10.2 µg P/5 g soil in H_2O solution with no buffer.

In addition to Piper's method, Lopez-Hernandez and Burnham (1974) used an adsorption index x/log C proposed by Bache and Williams (1971). A solution of phosphate (155 µg P/100 g soil), presumably KH_2PO_4 (although the compound was not stated in the article) was used from which P adsorbed was calculated by difference. The time of reaction was not indicated.

In contrast to the one-point isotherms discussed above, adsorption maxima have been determined from multipoint isotherms. Vijayachandran and Harter (1975) developed adsorption isotherms on a variety of soils using a 1 hr reaction time in order to obtain an index of "reactive" sites. Ryden et al. (1976) found however, that a reaction time of 40 hours was required for equilibrium to be attained. Most investigators have used a shaking time of 24 hours.

The trends indicated above indicate that Langmuir sorption parameters may be correlated with a measure of "active" Fe and Al. As previously discussed, k is related (in the Langmuir model) to the energy of adsorption of phosphate by solid surfaces. It is not considered to be a partition coefficient in that $K_{partition} = S/C$, where S = amount of phosphate adsorbed per weight of soil, and C = solution concentration of phosphate in equilibrium with the solid surface. As stated in a previous section, the Langmuir constant can be pictured in several ways. In the sense of energies of interactions, k can be written as

$$k = k_o e^{Q/RT} \qquad [6\text{-}17]$$

where, $k_o = N \sigma \tau_o/(2\pi MRT)^{1/2}$, N = Avagadro's number, σ = area of one adsorption site, τ_o = residence time of a molecule on the surface when there is no interaction between the molecule and the surface, M = molecular weight of the adsorbing molecule, R = gas constant, T = absolute temperature, and Q = interaction energy of the molecule with the surface (Adamson, 1976). The Langmuir k which is obtained from an adsorption experiment on a heterogeneous medium such as soil represents a composite of all adsorbing surfaces. That is,

$$Q_{total} = \sum_{i=1}^{n} x_i \, q_i = RT \ln \frac{k}{k_o} \qquad [6\text{-}18]$$

where Q_{total} is the total interaction energy per weight of composite, q_i is the interaction energy for a particular type of constituent per weight of constituent in the composite, and χ_i is the fraction of i in the composite. Thus, an increase in the value of the observed k may indicate that an increase in Q occurred.

Since the largest q_i for phosphate adsorption on soils appears to be due to "active" iron and aluminum oxyhydroxides, the expected trend for k would increase exponentially with the fractional composition of those "active" metals. However, as previously discussed, the measurement of the "active" fraction is difficult. Figure 6-3 shows that, in contrast to the expected trend, the k (normalized to Fe + Al) decreases in general with CDB extractable Fe and Al.

By similar considerations, one would expect that S_{max} normalized to extractable Fe + Al would be independent of extractable Fe and Al. Apparently the situation is not so simple as Fig. 6-4 illustrates.

Several authors have indicated that Fe and Al in active forms are responsible for sorption of phosphate. In addition to their summaries, phosphate sorption parameters and soil chemical properties which were collected in the present study have also been plotted. Table 6-4 summarizes these correlations. In general, our correlation, based on soils and rocks from several locations, show more significant results for 1) oxalate extractable Fe and Al and 2) sorption parameters normalized with respect to the corresponding extractable Fe and/or Al. These results agree with those of Saunders (1965) and Williams et al. (1958).

Data from several of the correlations in Table 6-4 were plotted (Figures 6-5 to 6-12) in order to determine visually the trends indicated in Table 6-4 and the variations among individual studies. The numbers plotted in the figures represent the REF in Table 6-2. It is readily seen that any relationship between sorption parameters and soil properties obtained by statistical analysis of one group of soils cannot necessarily be extrapolated to all soils. For example, the plot of ln S_{max} versus ln k in Fig. 6-5 shows that intercepts and slopes of linear regressions of the data are different for REF 3 and 8. Comparison of these references, shows that in the first case ln k is nearly independent of ln S_{max} whereas, in the second case ln S_{max} is independent of ln k. The differences apparently result from the inability to quantify active Al and Fe. Differences in pH may account for some of the variability.

Several conclusions can be drawn from the study of relationship between phosphate sorption parameters and selected soil properties. Oxalate extractable Fe and Al are more significantly related to the Langmuir phosphate sorption parameters than are CDB extractable Fe and Al. Oxalate extraction appears to be more suitable for measurement of the "active" Fe and Al than CDB. Variability among authors is quite high and thus indicates a need for standarization of Fe and Al analyses as well as methods for measuring phosphate sorption parameters.

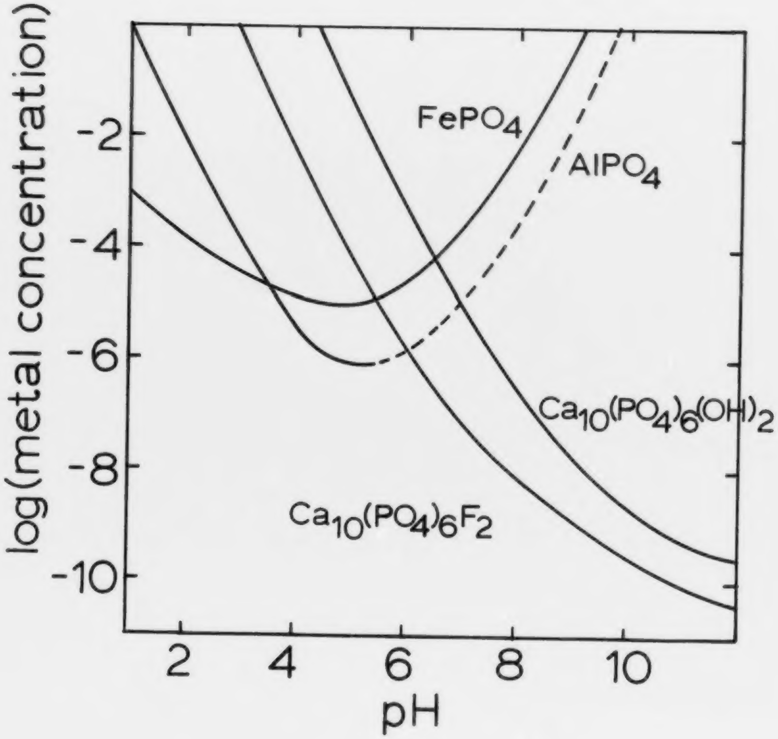


Figure 6-2. Solubility diagram for selected solid phosphate phases (Stumm and Leckie, 1971).

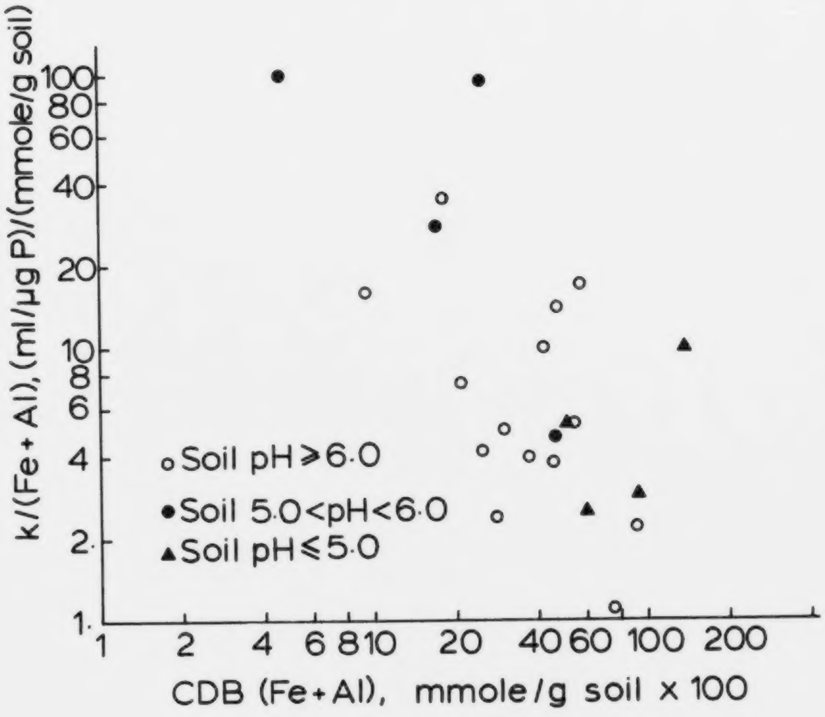


Figure 6-3. Relationship between Langmuir k normalized with respect to CDB extractable Fe + Al and CDB extractable Fe + Al for selected soils.

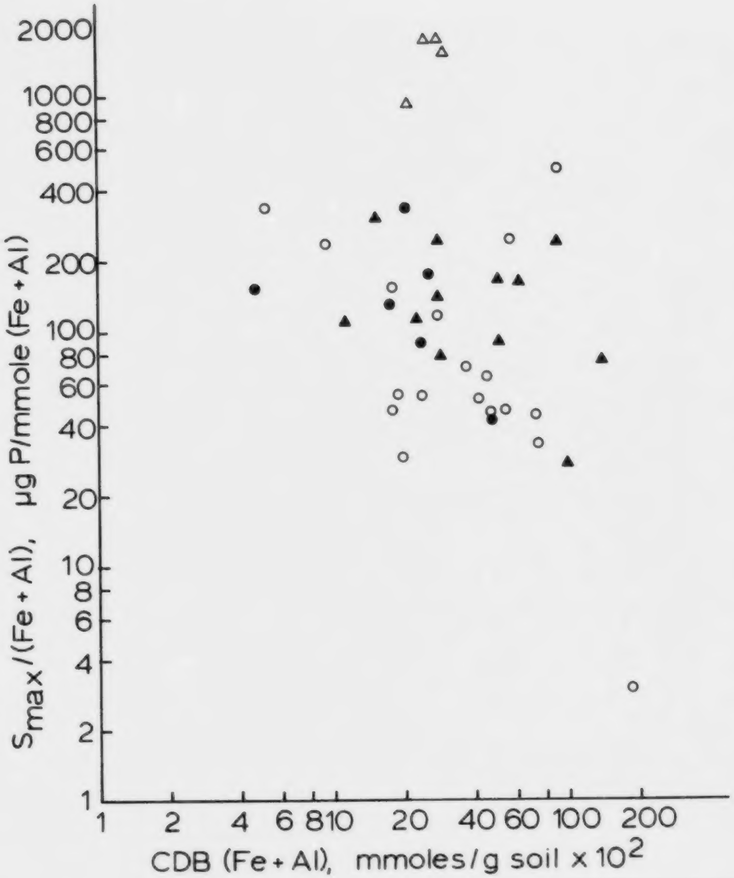


Figure 6-4. Relationship between normalized S_{max} and CDB extractable Fe + Al for selected soils.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table 6-4. Summary of estimates obtained from linear regression correlations of phosphate sorption parameters and extractable Fe and Al.

Dependent[*] Variable	Independent Variable	Inter-cept	Std. error of Intercept	Slope	Std. error of slope	PR>F[†], %	R^2	C.V.[††]
LNSMAX	LNFEAL1	6.26	0.25	0.503	0.184	1.01	0.18	15.6
	LNFEAL2	5.59	0.36	0.070	0.191	72.2	0.02	12.0
	LNFE1	5.98	0.37	0.449	0.217	4.46	0.09	23.6
	LNAL1	7.68	0.40	0.761	0.146	0.01	0.45	12.8
	LNFE2	5.55	0.42	0.033	0.171	85.3	0.004	12.1
	LNAL2	5.84	0.59	0.140	0.221	54.5	0.048	11.8
LNK	KNFEAL1	1.23	0.32	-0.186	0.276	51.1	0.03	64.6
	LNFEAL2	0.46	0.34	-0.414	0.180	5.1	0.40	56.2
	LNFE1	1.00	0.90	-0.937	0.542	9.6	0.11	101.7
	LNAL1	1.58	0.67	0.090	0.300	76.8	0.006	65.4
	LNFE2	0.28	0.37	-0.393	0.154	3.36	0.45	53.7
	LNAL2	0.063	0.62	-0.414	0.231	11.0	0.29	61.1
LNSMAX1	LNFE1	5.98	0.37	-0.551	0.217	1.5	0.13	18.5
LNSMAX2	LNAL1	7.68	0.40	-0.239	0.146	11.1	0.075	8.9
LNSMAX3	LNFEAL1	6.26	0.25	-0.497	0.184	1.09	0.18	13.2
LNSMAX4	LNFE2	5.55	0.42	-0.967	0.171	0.05	0.80	8.7
LNSMAX5	LNAL2	5.84	0.59	-0.860	0.221	0.46	0.65	8.1
LNSMAX6	LNFEAL2	5.59	0.36	-0.930	0.191	0.12	0.75	9.3
LNK1	LNFE1	1.00	0.90	-1.937	0.542	0.15	0.34	63.1
LNK2	LNAL1	1.58	0.67	-0.910	0.300	0.85	0.38	25.9
LNK3	LNFEAL1	1.23	0.32	-1.186	0.276	0.06	0.55	40.4
LNK4	LNFE2	0.28	0.37	-1.393	0.154	0.01	0.91	18.5
LNK5	LNAL2	0.06	0.62	-1.414	0.231	0.03	0.82	18.6
LNK6	LNFEAL2	0.46	0.34	-1.414	0.180	0.01	0.88	23.2
K	SMAX	280.6	99.0	-0.130	0.095	18.4	0.07	209.1
LNK	LNSMAX	8.44	1.17	-1.163	0.215	0.01	0.54	73.0

[*] Symbols for variables represent the following: SMAX = Lang. S_{max}; K = Lang. k; FE, AL = extractable Fe and Al, respectively; FEAL = extractable Fe + Al; suffixes 1, 2 on independent variable = citrate-dithionite-bicarbonate and oxalate extractant, respectively; suffixes on dependent variable = normalized variable with respect to the corresponding independent variable; LN = natural logarithm of variable.

[†] Probability level at which regression is significant. PR>F = 0.01% is equivalent to $\alpha = 0.0001$.

[††] Coefficient of variation.

TYPING GUIDE SHEET

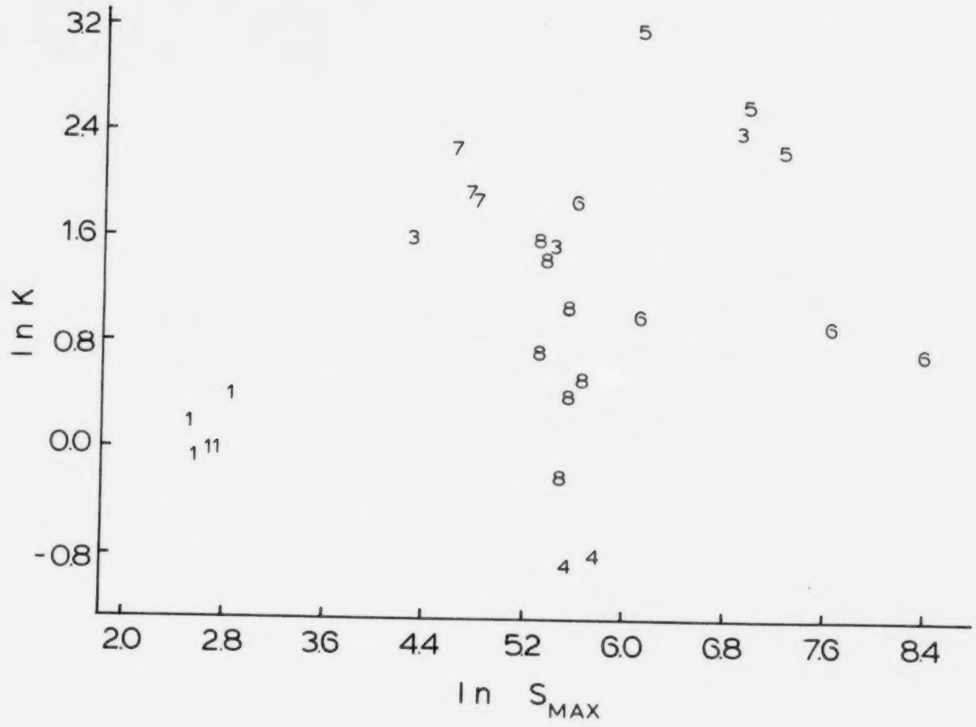


Figure 6-5. Relationship between lnk and $\ln S_{max}$ for selected soils. Numbers refer to REF in Table 6-2.

EPA-287 (Cin.)
(4-76)

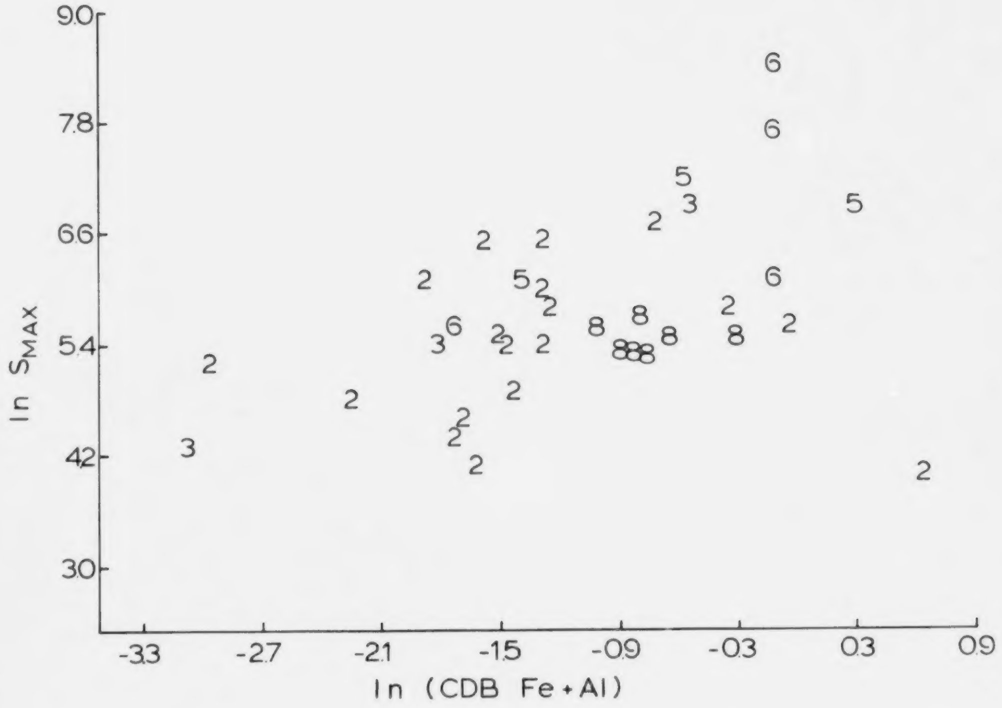


Figure 6-6. Relationship between $\ln S_{max}$ and ln CDB (Fe + Al) for selected soils. Numbers refer to REF in Table 6-2.

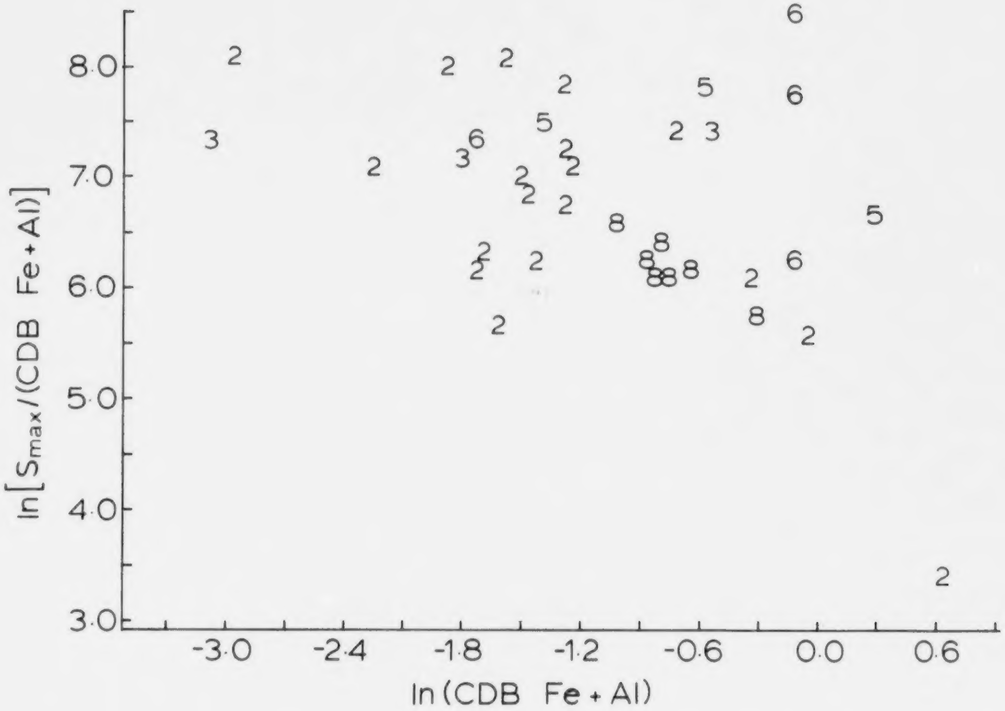


Figure 6-7. Relationship between $\ln[S_{max}/(CDB\ Fe + Al)]$ and $\ln(CDB\ Fe + Al)$ for selected soils. Numbers refer to REF in Table 6-2.

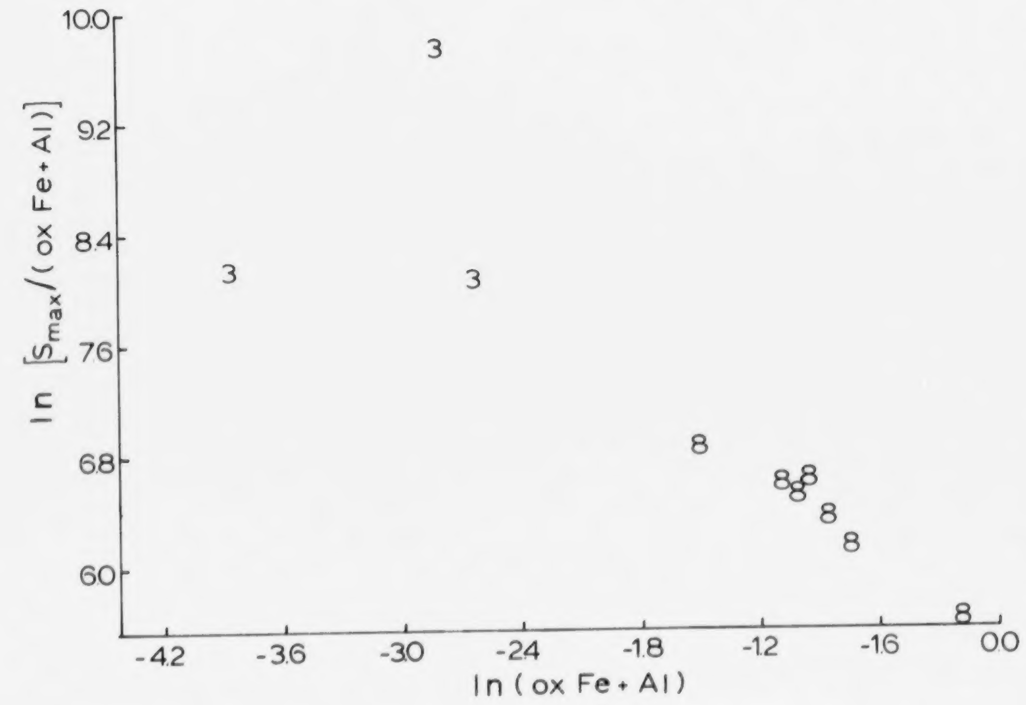


Figure 6-8. Relationship between $\ln[S_{max}/(oxFe + Al)]$ and $\ln(oxFe + Al)$ for selected soils. Numbers refer to REF in Table 6-2.

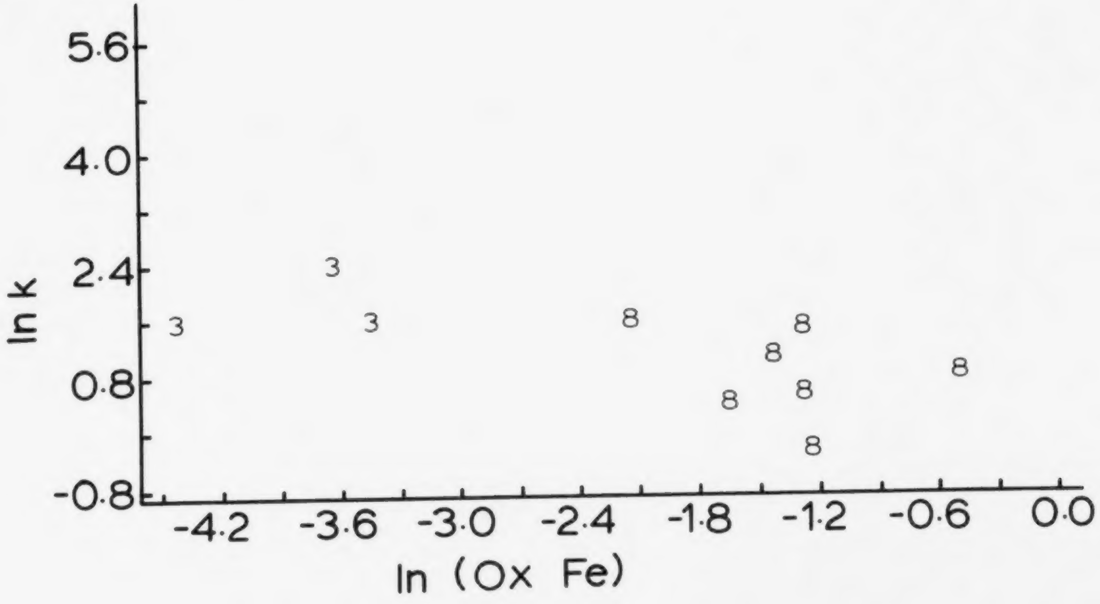


Figure 6-9. Relationship between lnk and ln(oxFe) for selected soils. Numbers refer to REF in Table 6-2.

TYPING GUIDE SHEET

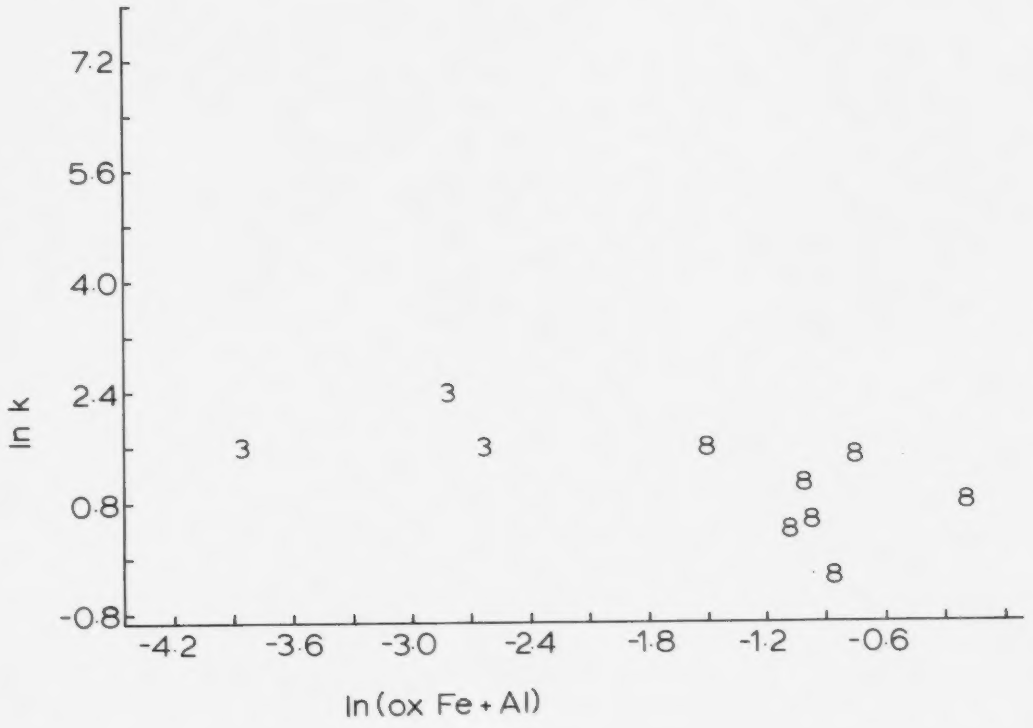


Figure 6-10. Relationship between lnk and ln(oxFe + Al) for selected soils. Numbers refer to REF in Table 6-2.

EPA-287 (Cin.)
(4-76)

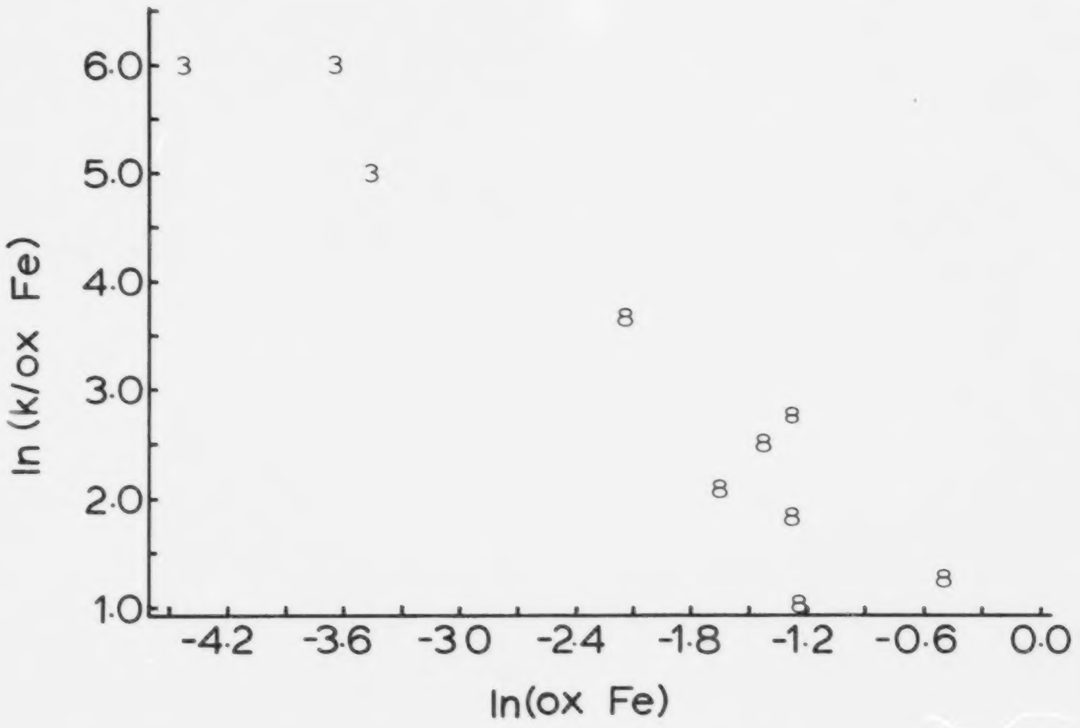


Figure 6-11. Relationship between ln(k/oxFe) and ln(oxFe) for selected soils. Numbers refer to REF in Table 6-2.

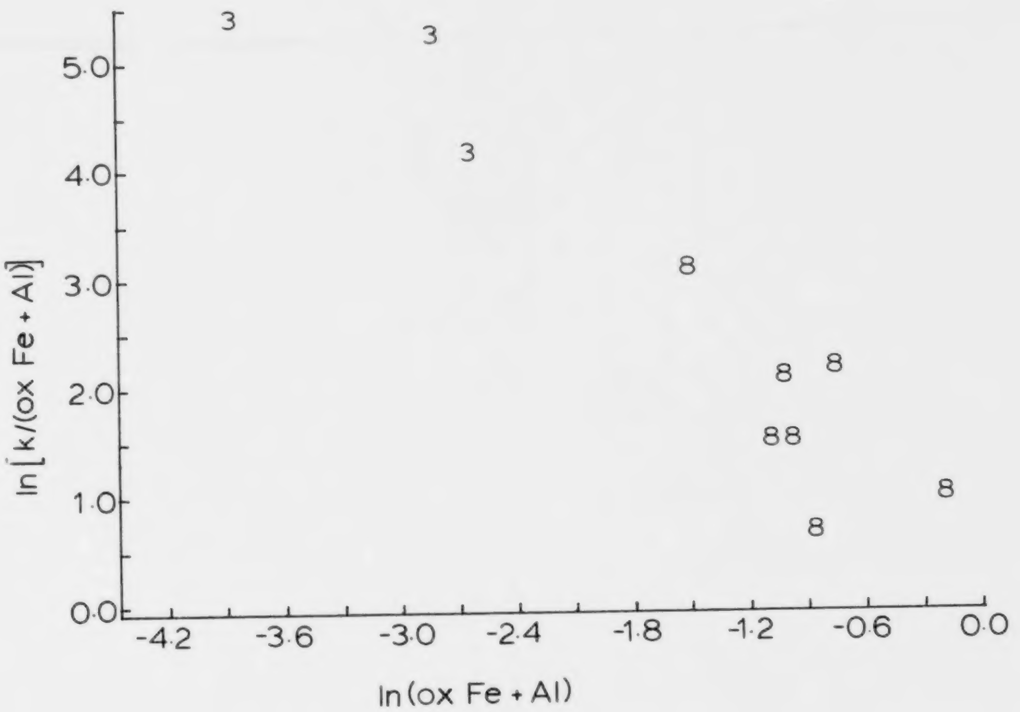


Figure 6-12. Relationship between ln[k/(oxFe + Al)] and ln(oxFe + Al) for selected soils. Numbers refer to REF in Table 6-2.

ESTIMATION OF A PARTITION COEFFICIENT FOR PHOSPHATE

We describe here the first known attempt to develop a phosphate partition function K_D which is based on soil chemical properties. The Langmuir equation is used as the adsorption model and literature data are used to compute values for K_D. Because of extreme variability in the relationship between soil chemical parameters and phosphate sorption, the attempt did not successfully describe K_D in a meaningful way.

A partition coefficient K_D which describes the relation between solid forms of phosphate (adsorbed phosphate and precipitated phosphate compounds) and solution phosphate ideally can be expressed in terms of Langmuir sorption parameters. Conditions which effect the magnitude of K_D include: 1) phosphate concentration in the solution in contact with the solid phase, 2) time after which phosphate has been placed in contact with soil before a desorption event, 3) time elapsed during a desorption event, 4) solution pH, and 5) soil chemical properties. Amounts and crystallinities of Fe and Al hydrous oxides appear to dominate other properties in acid soils, and solution Ca^{2+} concentrations in basic soils are significant.

Although there appears to be no sound theoretical basis for using the Langmuir equation to describe ionic adsorption by solids in aqueous systems, the model allows the calculation of parameters which are useful on an empirical basis. The Langmuir equation is used as a mathematical model in this report, primarily because of the large volume of Langmuir sorption parameters reported in the literature. Other equations (Freundlich, Temkin) are being tested to determine their usefulness in computing a K_D.

A partition function for phosphate sorption for a single soil can be described by the Langmuir equation. Rearrangement of the Langmuir equation gives for the partition coefficient, K_D,

$$K_D = \frac{S}{C} = \frac{kS_{max}}{1 + kC} \qquad [6\text{-}19]$$

Based on this equation, K_D is a function of the equilibrium solution concentration of phosphate. A few computations using the data in Table C31 show that the dependence of K_D upon C follows the expected trend.

However, if $kC << 1$, Eq. (6-19) can be put into the form,

$$K_D = \frac{S}{C} \sim kS_{max} \qquad [6\text{-}20]$$

In this approximation, K_D is independent of C, and S is directly proportional to C. Thus, Eq. (6-20) represents a linear adsorption isotherm or the Freundlich equation in which the exponent of C is equal to 1. Figure 6-13 shows a plot using data from Tables C22 and C31 which illustrates the suitability of this approximation. Large deviations from the linear plot occur in the soil with the higher k.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

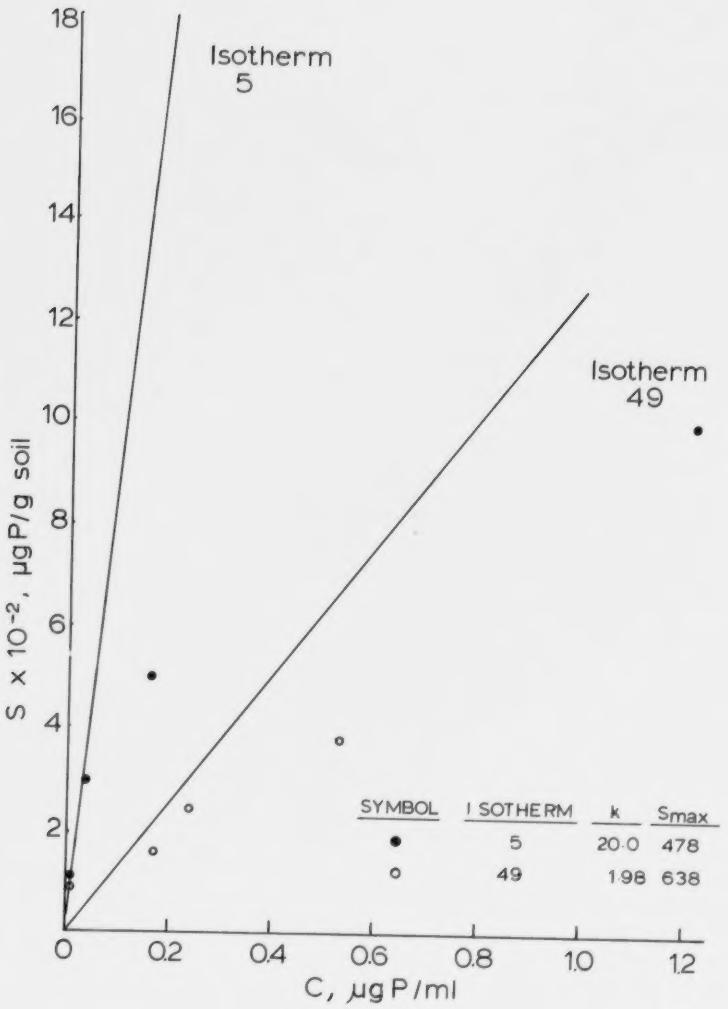


Figure 6-13. Phosphate sorption isotherms for isotherms 5 and 49 (Table C22). Solid lines were computed from $S = kS_{max}C$ using the parameters indicated in the figure.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

Errors involved in using Eq. (6-20) can be evaluated by combining Eq. (6-19) and Eq. (6-20) to give

$$S'/S = 1 + kC \qquad [6\text{-}21]$$

where $S' = kS_{max}\,C$, and S comes from Eq. (6-19). The quotient S'/S represents the degree to which S' approximates S. Figure 6-14 shows a plot of Eq. (6-21) as a function of C up to 2 μg P/ml in the equilibrium solution (a reasonable limit of phosphate concentrations in soils) for various values of k. A factor of 2 was taken to be a reasonable limit for S'/S. The figure shows that for low values of k (examples can be taken from Tables C10 and C22), S'/S is small, and S' thus represents an acceptable approximation to S. As long as the solution concentration of P is equal to or less than 1/k, an acceptable error results.

Prediction of phosphate sorption behavior and a partition function on an unknown soil is associated with appreciable errors. The above treatment has regarded K_D ($=kS_{max}$) as an intrinsic property which is characteristic of the behavior of a given soil. K_D values, estimated from the compilation of data in this report, were found to range from 100,000 ml/g soil to 1.0 ml/g soil. A mean K_D plus or minus a standard error would appear to have less than desirable value in describing adsorption-desorption behavior.

We attempted unsuccessfully to quantify K_D as a function of 1) extractable Al and/or Fe, 2) pH, and 3) exchangeable Ca^{2+} content of soils using literature data. Several soil chemical parameters, which are difficult, if not impossible, to quantify from the literature, introduce variability in K_D. Figure 6-15 shows a plot of K_D and CDB extractable Fe + Al. The correlation between K_D and CDB Fe + Al is not satisfactory, as would be expected from the statistical analyses presented in the previous section which indicate a probable relationship between k and S_{max}. Normalization of K_D with respect to CDB Fe + Al yields similar results as shown in Figure 6-16. Degree of crystallinity of Fe and Al oxhydroxides and the concentration range to which K_D applies (i.e., whether $kC << 1$) also introduce variabilities in K_D.

Because of the concentration dependence of K_D, another factor which affects its magnitude is the elapsed time after an adsorption or desorption event. During this time the phosphate comes to equilibrium with the soil solution. Barrow and Shaw (1975) have given a semiempirical relationship which included the times during which added phosphate came to equilibrium with the soil and the time during which desorption occurred. Their model is described in more detail in a later section.

An important feature of their model described both adsorption and desorption limbs of the isotherm as they changed with time of incubation with 100 μg P/g soil. Figure 6-17 illustrates the non-singularity involved in such adsorption experiments on one soil. An estimate of the amount of phosphate entering the soil solution during a desorption event can be obtained from such a plot if S and C are known when the desorption begins. Kinetics of the adsorption and desorption apparently control the degree of non-singularity. Table 6-5 lists the approximate K_D values obtained at various times for soil incubated for 18 days at 42°C with 1000 μg P/g soil, and solution:soil ratios

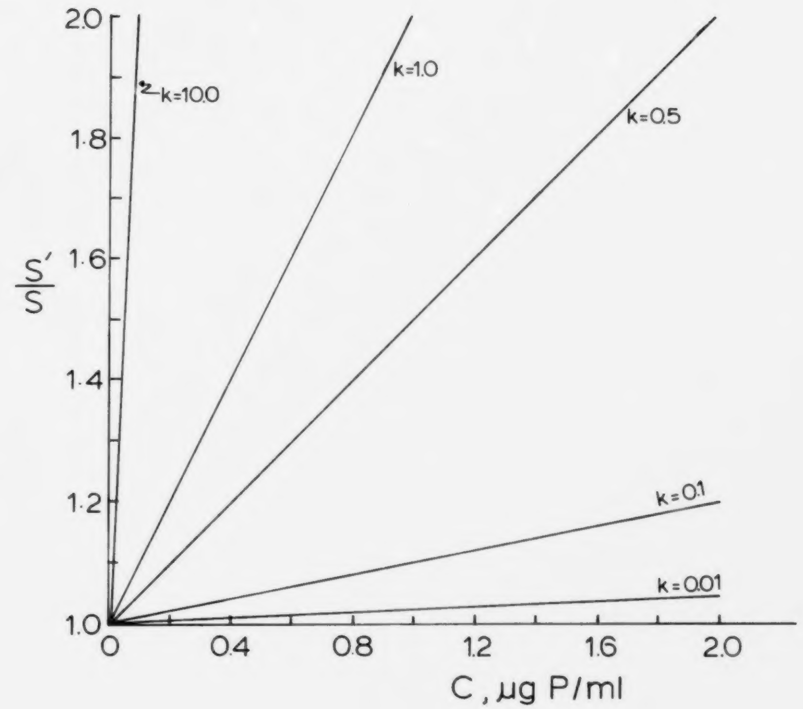


Figure 6-14. Degree of error in using $S' = kS_{max}C$ compared to the Langmuir form, $S = kS_{max}C/(1 + kC)$, as a function of equilibrium phosphate concentration for various values of k.

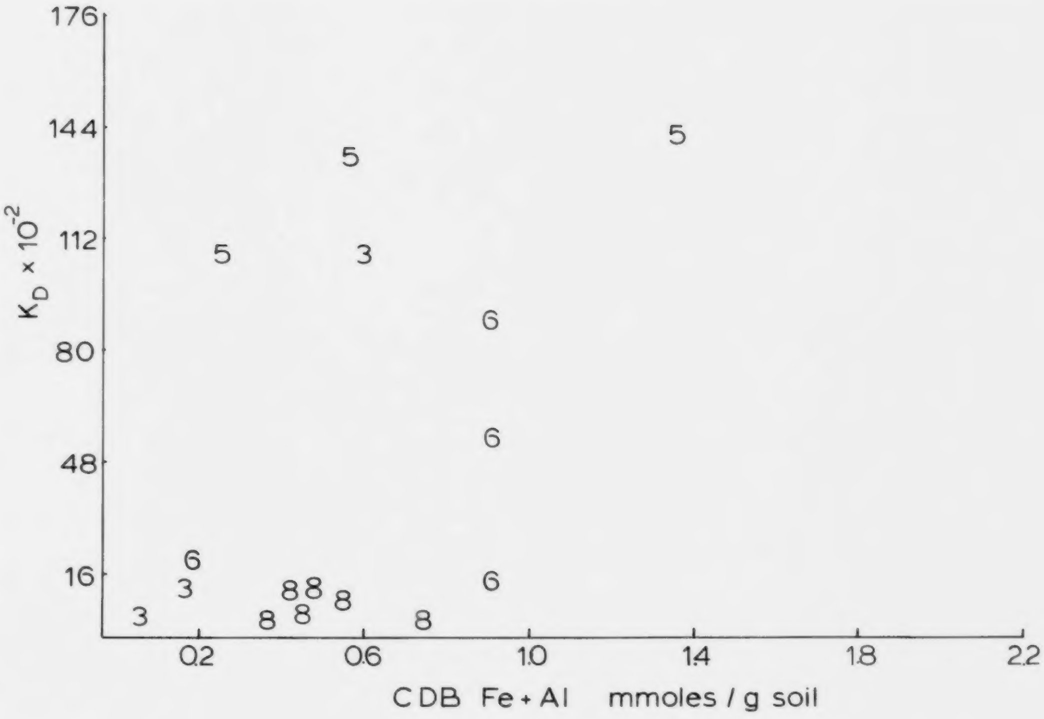


Figure 6-15. Relationship of the approximate expression for $K_D(=kS_{max})$ and CDB Fe + Al for selected soils. Numbers refer to REF in Table 6-2.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

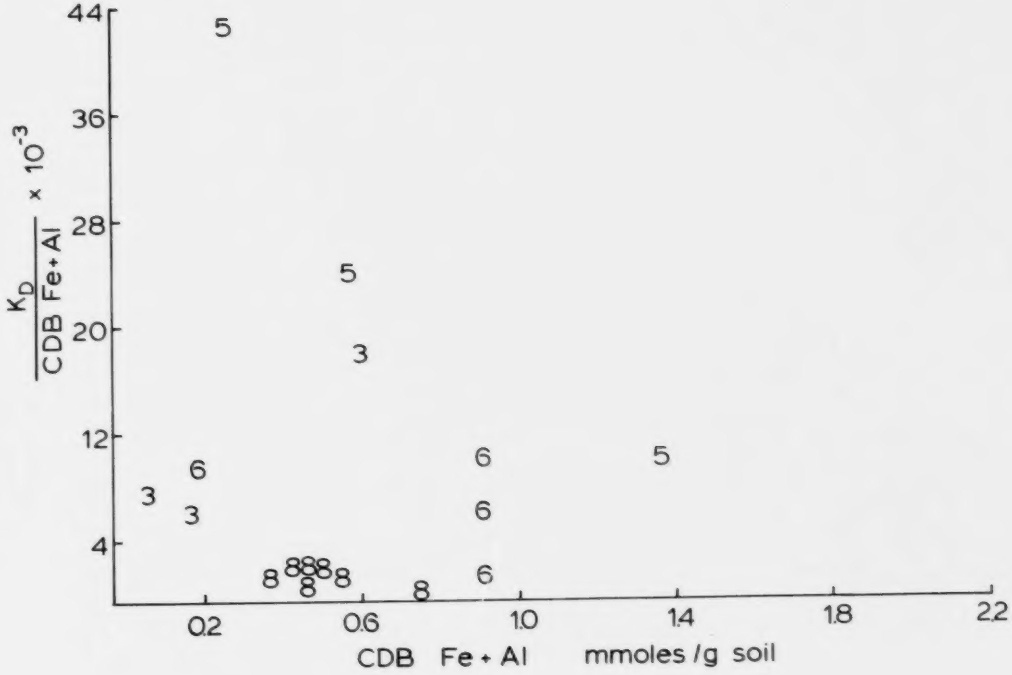


Figure 6-16. Relationship of the approximate expression ($K_D = kS_{max}$) normalized with respect to CDB Fe + Al and CDB Fe + Al for selected soils. Numbers refer to REF in Table 6-2.

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

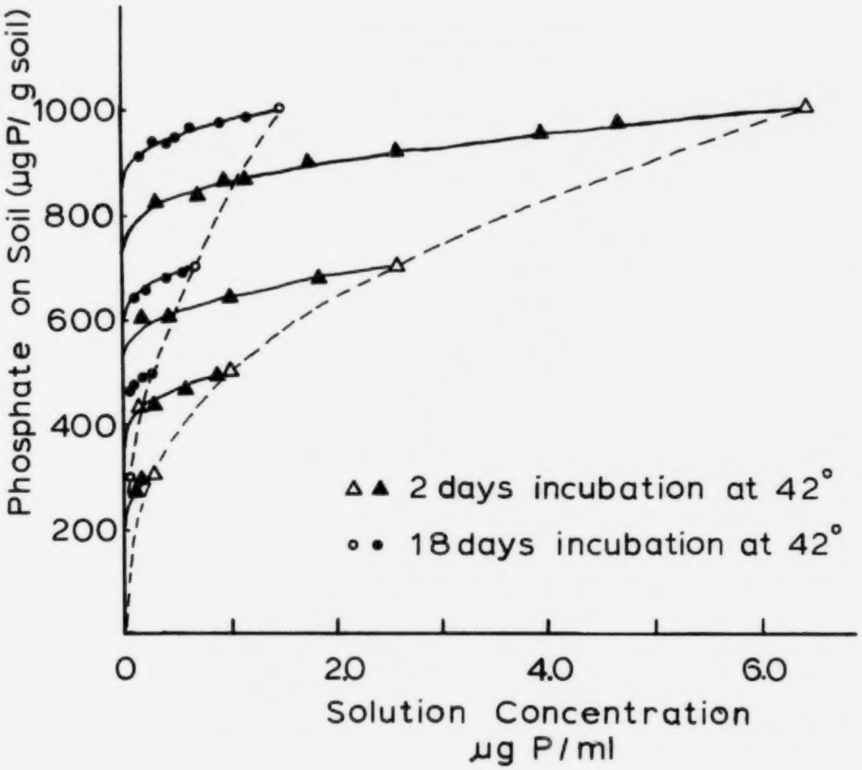


Figure 6-17. Phosphate sorption-desorption isotherms for a soil incubated in the presence of phosphate (Barrow and Shaw, 1975).

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

Table 6-5. Effects of time of desorption and solution/soil ratio during desorption on K_D values obtained on a soil previously incubated with phosphate.

Soln.: Soil ratio	Time, hr	K_D, ml/g soil
5:1	1	1,245
	4	828
	8	620
500:1	2	11,127
	6	8,120
	17	5,750

EPA-287 (Cin.)
(4-76)

of 5:1 and 500:1. Lack of kinetic data prevents evaluation of this effect on a broad scope of soils. The following conclusion can be arrived at on the basis of the analysis presented in this section.

1. A standardized method for determination of sorption parameters is required in order for consistency from laboratory to laboratory.

2. A partition coefficient can be calculated as the product kS_{max}, based upon the assumption that the Langmuir equation expresses the true adsorption. This product allows the estimation of solution-soil partitioning of phosphorus up to a solution concentration equal to 1/k within a factor of two.

3. The K_D normalized with respect to extractable Fe + Al is not significantly related to Fe and Al as in the case of pesticide adsorption described by k_{oc}.

PHOSPHATE IN RUNOFF WATERS

Modeling phosphate concentrations in runoff waters requires a knowledge of 1) quantities of phosphate already present in the soil, 2) distribution of phosphate with particle size of the soil, 3) the rate at which phosphate is released from soil, and 4) the quantity released during the time of a desorption event. A review has recently appeared which discusses transformations and quantities of phosphate in runoff (Logan, 1980).

The effect of the quantity of phosphate already present in the soil has been considered by Barrow and Shaw (1975) and was discussed in the previous paragraph (Fig. 6-17). Apparently, phosphate was held in a less soluble form after soil with added phosphate was incubated. The fraction of phosphate released from the soil during the equilibrium desorption experiment varied from 0.03 to 0.16 (Fig. 6-17). Thus, based on the data by Barrow and Shaw (1975), a soil containing 500 mg P/g soil, may be expected to release 15 mg P/g soil in equilibrium with a solution containing 2 mg P/ml.

Runoff sediments become enriched in finer particle-size fractions and the phosphate is more concentrated in the sediment because of its association with silt and clay fractions. The particle size distribution of the runoff sediment is a function of the erosion rate, nature and geomorphological position of the soil (Logan, 1980). Plant nutrients, including phosphate, were enriched in the finer fractions of sediments when compared to concentrations existing in the soil before erosion (Stoltenberg and White, 1953). Total phosphate was also concentrated in the silt and clay fractions of two New Zealand soils (Syers et al., 1969). An approximately linear relationship between available phosphate in eroded sediment and solution phosphate concentration was found in a controlled field plot study on a Russell silt loam soil (Romkens and Nelson, 1974). They proposed a simple laboratory test to measure phosphate concentration in runoff water. The method involved overnight equilibration of soil with 0.1 N NaCl and measurement of extract phosphate. However, this measurement was not related to soil chemical properties.

The rate at which phosphate is released from the soil was discussed in the previous paragraph (Table 6-5).

EXPERIMENTAL CONDITIONS WHICH AFFECT MEASUREMENT OF PHOSPHATE SORPTION PARAMETERS

In selecting parameters for the phosphate adsorption model, standardization of measurement procedure by which the parameters are measured seems to be of first concern. The following are the factors which need to be taken into consideration.

a) Temperature effect. In relating the amount of phosphate adsorption to solution concentration, constant temperature is essential because the relationship is temperature dependent. Gardner and Jones (1973) equilibrated an Aridisol (Calciorthid) and a Spodosol (Fragiothod) from Idaho with a $0.01\underline{M}$ $CaCl_2$ solution containing varied amounts of phosphate at 5° and 20°C and found that the adsorption rate decreased as the equilibration temperature was lowered. The rate of desorption was affected similarly. They found phosphate in the equilibrated solution at 5° and 20°C. The reduction reached 23 and 15%, respectively, for Fragiorthod and Calciorthod with high phosphate pretreatment. Barrow and Shaw (1975) conducted experiments in which soils with varying amounts of added phosphate were incubated at different temperatures. The amount of phosphate extracted by shaking 15 minutes in $0.01\underline{M}$ $CaCl_2$ decreased as incubation temperature increased. Conversely, when soils were incubated at one temperature and phosphate was measured at another, an increase in temperature of measurement resulted in high solution concentrations of phosphate. Both of these effects can be explained on the basis of kinetics of phosphate transformation from an adsorbed to a crystalline precipitate phase in a system which is not at true equilibrium when measurements were taken.

b) pH effect. As the pH of the soil usually affects the chemical reactivity of some soil constituents, its effect on phosphate adsorption has been taken into consideration in many phosphate sorption studies. There were studies where no attempt was made to control the pH of the suspension, as Table C23 indicates. Bache and Williams (1971) obtained the value of their proposed single-point phosphate sorption index, x/log c, for a limed field soil at pH 6.5 which differed only by 3% from the value obtained on its unlimed analogue at pH 4.3. They suspected that the effects of pH in the range normally encountered in acid soils are likely to be small compared with differences between soils. Lopez-Hernandez and Burnham (1974b) did not find a significant correlation between pH and phosphate retention for a group of mixed soils but they did find a highly significant decrease in retention with increasing pH for a group of pedologically similar soils differing mainly in pH. In an earlier study, Obihara and Russell (1972) showed that the amounts of phosphate adsorbed by the soils decreased substantially with increasing pH with two breaks in the curves at about pH 6.4 and 11.6.

c) Salt effect. In phosphate adsorption studies, phosphate has often been added with an electrolyte, usually a neutral salt such as NaCl, KCl, or $CaCl_2$. A recent study by Helyar et al. (1976) showed that the phosphate adsorption isotherm for a 1% gibbsite suspension in the equilibrium phosphate concentration range of 0.1 to 1000 μM was not affected by the presence of 0.02M NaCl or KCl or 0.01M $MgCl_2$. However, increasing $CaCl_2$ from 0 to 0.02M increased the phosphate adsorption over the range of 1-100 μM final phosphate concentration after 24 hours of equilibrium at pH 5.5 and 26°C. They proposed that the affect of Ca on phosphate adsorption was not due to bulk precipitation of di- or octo-calcium phosphate but rather epitaxial complexation of $2(H_2PO_4^-)$ ions with Ca^{2+} on the 001 surface of gibbsite. Ryden and Syers (1975) and Ryden et al. (1977) working with soils found that ionic strength and cation species influenced the amount of adsorption throughout the final phosphate concentration range of 0 to 10 μg P/ml during 40 hours of contact. At infinite time, the equilibrium concentration was independent of ionic strength and cation species. They concluded that the composition of the solution affected only the rate at which equilibrium was attained. Singh and Tabatabai (1978) equilibrated 3 g of soil with 30 ml of 0.01M solutions of various salts containing 0-50 μg P/ml by shaking at 23°C for 24 hours and found that chlorides of K, Na, Li, Ca, and Mg, Ca sulfate and nitrate, and $KHCO_3$ increased the phosphate adsorption by 6 soils they used.

d) Time effect. It has been generally agreed upon from the kinetic studies that phosphate adsorption involves two stages of reaction; the first proceeds rapidly and the second may continue for many weeks or months. The initial rate of adsorption is complete within a few hours and a slower reaction continues for longer periods. The time required to establish equilibrium depends on the soil and clay materials. The equilibrium time used by various workers ranged from 16 hours (Larsen and Widdowson, 1964) to 48 hours (Ryden et al., 1977). Hope and Syers (1976) found that phosphate adsorption isotherms of three soils with widely different phosphate adsorption capacities showed a dependence on solution to soil ratio at a final phosphate concentration of 0.5 μg P/ml after 40 hours of contact. However, adsorption equilibrated continued in samples up to 146 hours. Ryden et al. (1977) found an initially rapid decrease in solution phosphate concentration with soils, hydrous Fe oxide gel, and natural goethite. It was followed by a much slower decrease between 43 and 192 hours. They concluded from the resolution of the sorption isotherms that the increase in phosphate sorption with time involved an appreciable shift of phosphate from a more physically sorbed form to a chemisorbed from involving the diffusion of phosphate into "structurally porous" amorphous material.

e) Effect of accumulation of CO_2 and aeration. The redox status of soil suspensions while shaking or stirring has been shown to be an important factor in the sorption and release of phosphate (Patrick and Khalid, 1974). The degree of aeration is also important in order to prevent accumulation of CO_2 in the sample containers. The variability of CO_2 concentrations in soil solutions causes a variation in equilibrium phosphate concentrations (Larsen and Widdowson, 1964).

f) Concentration range. Concentration ranges of phosphate used by various authors in phosphate adsorption studies varied considerably. Both low and high concentration ranges have practical values. While the low ranges reflect the phosphate concentration in soil solution, the high concentration range may simulate the situation which may be found in the fertilizer zone. Rajan (1975) found several inflection points in the phosphate adsorption isotherms when a large amount of phosphate was added. Effects on K_D were discussed in a previous section.

g) Solid to solution ratio. The effect of solid to solution ratio on phosphate adsorption has been noted (Larsen and Court, 1960; Fordham, 1963). However, a great variation in the solid-solution ratio has been found in published reports. Larsen and Widdowson (1964) studied the soil to solution ratio effect on equilibrium phosphate concentration in $0.01\underline{M}$ $CaCl_2$ solution in their phosphate potential study and suggested that the ratio effect was induced by CO_2 due to a variation in biological activity and soil aeration. The effect of CO_2 on phosphate adsorption and release was interpreted by Patrick and Khalid (1974) as resulting from microbial reduction of Fe^{3+} insoluble phosphates to the more soluble Fe^{2+} form. Recently, Hope and Syers (1976) found that more phosphate was adsorbed by the soil at a soil/solution ratio of 1:5 than 1:40 for a given level of phosphate above a final concentration of 0.5 μg P/ml. However, the phosphate adsorption from various soil/solution ratios appeared to be the same at equilibrium when the phosphate concentration was estimated by extrapolation of the linear relationship between solution phosphate and the reciprocal of time to zero (or $t \to \infty$).

h) Effect of previously accumulated phosphate. Bache and Williams (1971) have shown that the same two soils with different amounts of previously sorbed phosphate gave two different adsorption isotherms. When the initially sorbed phosphate was taken into consideration, the two isotherms became coincident. Barrow (1974) showed that after 12 months of incubation and 3 years in the field, previous phosphate additions reduced the capacity of the soils to adsorb further phosphate. Previously sorbed phosphate was less exchangeable which suggested that it had been converted into a form which occupied the sites and blocked them from further reaction. The effect, however, was not linear. Low levels of phosphate application produced a larger effect per unit of added phosphate than high levels.

Isotopically exchangeable phosphate

In order to develop a measurement of the amount of phosphate available to plants, several workers have adapted radioisotopic techniques to soil phosphate chemistry. Such experiments record the fraction of the radioisotope (usually ^{32}P-labelled phosphate) left in solution after a period of equilibration. The technique has several advantages from an experimental point of view; however, interpretations of the disappearance of the radioisotope from solution vary among authors. Advantages of the radioisotope method have included: 1) the absence of complexing reagents, acids, or bases commonly employed for phosphate extracting which alter the chemical composition of the soil-water system (Amer et al., 1955), and 2) the potential of the method to distinguish between the various mechanisms of phosphate disappearance (Russell et al, 1954; Lieser, et al., 1945). However, the mathematical treatment of the isotopic exchange kinetics is usually based upon an equation for a group of simultaneous first order reactions (Russell et al., 1954), or expressions which include a consideration for the diffusion of the ion to the reacting surface (Lieser, 1945). The formulations based upon phenomenological classification of reactions provide little insight regarding reaction mechanisms as in the case of mechanistic formulations in reaction kinetics.

Disappearance of radioisotope labelled phosphate from solutions apparently follows a similar reaction sequence as unlabelled phosphate. That is, the radioisotope unremoved by a rapidly exchangeable pool of phosphate in hydroxyapatite slurries reduced ^{32}P activity to solution levels of 10% of the initial activity after 100 minutes of reaction time. Slower disappearance continued for 400 minutes (Avnimelech, 1968). The rapidly exchangeable ^{32}P was assumed to be complete within a few seconds after dilution. An intermediate pool continued for several minutes, and a slow pool removed ^{32}P from solution for several hours. The three reactions occurred simultaneously, of course. The author suggested that the intermediate pool was identical with a layer on the surface of the original mineral.

Experiments with soils have generally shown that a slowly exchanging and a rapidly exchanging fraction exists under field conditions. The process of isotopic reaction with the rapidly exchanging fraction is complete within 24 hours while the slower exchange reaction occurs for longer periods (Talibudeen, 1958).

The radioisotope-exchange technique has also been used to estimate existing adsorbed phosphate in soil matrices (Holford et al., 1974; Bache and Williams, 1971). From the relation (3-22), adsorbed phosphate can be estimated.

$$P_e = P_{sol} + P_s = P_{sol}/F \qquad [6\text{-}22]$$

where P_e = total isotopically exchangeable P, P_{sol} = total phosphate in solution (including nonradioactive species), P_s = isotopically exchangeable adsorbed phosphate, and F = fraction of radioactive phosphate exchange after 24 hours. This treatment assumes that only surface adsorbed phosphate is measured.

MATHEMATICAL EXPRESSIONS USED TO DESCRIBE TIME-DEPENDENCE OF PHOSPHATE SORPTION

In describing the time-dependence of phosphate sorption-desorption by soils, most researchers apply rate expressions commonly used in dealing with solutions. Extrapolations of these expressions to the case of solution-solid kinetics presents several problems. The concentration terms in kinetics expressions implies that any molecule or ion of reactant is capable of reaction. In liquid-solid systems however, only those atoms or ions in the surface layer and not those in the interior of the particle are available to react. Thus, a factor describing the concentration of reactive surface sites should be included in such rate expressions. An alternative approach has been used which expresses surface concentrations of phosphate in terms of an adsorption model.

Several attempts of describing the kinetics of phosphate sorption-desorption have been reported in the literature and are summarized in this section. Rate expressions derived from simple reaction schemes appear to describe the phenomenon of phosphate sorption rather than the mechanism of the sorption process. No studies were found which reduce the solution-solid system to a set of elementary reactions from which the rate law was derived. In general, it is not possible to deduce the mechanism of a reaction from the rate law alone (Smith, 1970). Other experimental methods such as spectroscopy must be used to fully elucidate the reaction mechanism.

However, the rate laws described in the literature for the sorption of phosphate do allow the experimenter to empirically calculate the importance of several variables relative to phosphate partitioning. Of these variables, the presence of certain mineral species and their crystallinities, time, and temperature seem to be the most influential in controlling phosphate sorption-desorption.

Several authors have developed mathematical expressions to describe the appearance and disappearance of phosphate from solutions in contact with solids of various compositions. One form of the rate expression is the parabolic diffusion law (Laidler, 1965) which may be written as

$$C = R\sqrt{t} + a \qquad [6\text{-}23]$$

where C is the quantity of substance appearing in solution in time t, R is a measure of diffusion and a is a constant. Cooke (1966) used an empirical relation Eq. (6-24) to describe phosphate release from British agricultural soils; his equation is as follows:

$$P = R\sqrt{t} + b \qquad [6\text{-}24]$$

Where P is the quantity of phosphate released in time t, R is a measure of a diffusion and b is a constant. Both R and b were suggested to describe capacity and intensity factors of the soil to supply phosphate to the soil solution. Unfortunately, no correlation of R or b with soil chemical parameters was reported. Their results indicated that phosphate release was diffusion controlled.

Another form of Eq. (6-23) was used by Evans and Jurinak (1976) to describe phosphate release from a desert soil with high pH and carbonate content. In their experiments, release of phosphate from the soil to an anion exchange resin was followed with time according to a scheme involving three simultaneous first order reactions outlined by Amer et al. (1955). A kinetic expression for each reaction may be reduced to

$$\log (C_o - C) = \log C_n - k_n t \qquad [6\text{-}25]$$

where C_o is the initial amount of unadsorbed phosphate present which participates in the nth reaction (C_o is equal to $\sum_{i=i}^{n} C_i$), C is the amount of phosphate released from the soil and adsorbed by the resin after time t, k_n is the rate constant of reaction n, and C_n is the amount of phosphate initially present for reaction n in the unadsorbed phase.

For the soil used by Evans and Jurinak, analysis of the data showed that the phosphate release could be adequately described by three simultaneous first-order reactions. Reaction durations were reported at approximately 1 to 2 hours, 8 to 16 hours, and 2 to 4 days, respectively. Rate constants and activation energies from the studies are listed in Table 6-6.

The above treatment by Evans and Jurinak was derived from the considerations of Amer et al. (1955). In Amer's treatment, three "desorption" reactions (reactions which cause appearance of phosphate in solution) were assumed to occur simultaneously. Phosphate desorbed from the soil into solution was adsorbed by an anion exchange resin and could be designated as P_{r1}, P_{r2} and P_{r3}, respectively for each of the fast, intermediate, and slow reactions. The fundamental rate expressions relating phosphate adsorbed by the resin with time were as follows:

$$\frac{d\,P_{r1}}{dt} = k_1{}' P_{s1} \qquad [6\text{-}26]$$

$$\frac{d\,P_{r2}}{dt} = k_2{}' P_{s2} \qquad [6\text{-}27]$$

and

$$\frac{d\,P_{r3}}{dt} = k_3{}' P_{s3} \qquad [6\text{-}28]$$

where P_{ri} are as described above, k_i' are rate constants, and P_{si} are the amounts of unadsorbed soil P that are present at time t. Integration of the above expressions gave $P_{ri} = C_i\ (1 - e^{-kit})$ with $P_{si} = C_i - P_{ri}$; when the three resulting expressions are combined equation (6-29) resulted:

$$P_r = P_{r1} + P_{r2} + P_{r3} = (C_1 + C_2 + C_3) -$$

$$(C_{1e}^{-k_1't} + C_{2e}^{-k_2't} + C_{3e}^{-k_3't}) \qquad [6\text{-}29]$$

where C_i are the amounts of unadsorbed phosphate remaining on the soil associated with each reaction at t = 0. By a series of computations, the three rate constants were evaluated to give $k_1 = 2.6 \times 10^{-3}\ \text{sec}^{-1}$, $k_2 = 1.25 \times 10^{-4}\ \text{sec}^{-1}$, and $k_3 = 4.2 \times 10^{-6}\ \text{sec}^{-1}$ for four Iowa soils.

Another rate expression was given by Kuo and Lotse (1974) for phosphate sorption by kinetic and gibbsite. Their treatment was based upon the Freundlich adsorption equation and was written

$$\frac{dP}{dt} = -k(P_o - P) \qquad [6\text{-}30]$$

Table 6-6. Rate constants and activation energies for indigenous phosphate release from Thiokol silt loam.*

	Surface soil:0-3 cm			Subsoil:28-40 cm		
	11°C	25°C	40°C	11°C	25°C	40°C
k_1 (sec^{-1})	$.19x10^{-4}$	$.51x10^{-4}$	$.30x10^{-4}$	$.24x10^{-4}$	$.41x10^{-4}$	$.41x10^{-4}$
k_2 (sec^{-1})	$.11x10^{-5}$	$.27x10^{-5}$	$.16x10^{-5}$	$.15x10^{-5}$	$.11x10^{-5}$	$.26x10^{-5}$
k_3 (sec^{-1})	$.87x10^{-6}$	$.13x10^{-6}$	$.12x10^{-6}$	$.15x10^{-6}$	$.93x10^{-6}$	$.19x10^{-6}$
ΔE_{d1}(kcal/mole)		2.8			3.3	
ΔE_{d1}(kcal/mole)		2.3			3.3	
ΔE_{d1}(kcal/mole)		2.0			1.7	

*From Evans and Jurinak (1976).

where P is the amount of phosphate in solution, P_o is the amount of phosphate already adsorbed by the soil, and k is the rate constant. The factor $(1 - e^{-k_2t})$ was inserted into the Freundlich equation ($x = kC^{n/m}$) to give

$$x^m = k(1 - e^{-k_2t})C^n$$

where x was the amount of phosphate adsorbed per gram of soil, k was the Freundlich constant, k_2 was the rate constant, C was the solution phosphate concentration, and m and n were constants. Rearrangements and transformations led to the expression

$$x = A^{1/m} C^{n/m} t^{1/m} \qquad [6\text{-}31]$$

where $A = kk_2$.
Eq. (6-31) was approximated by

$$x = kC_o t^{1/m} \qquad [6\text{-}32]$$

where C_o was the initial phosphate concentration, and $kC_o = A^{1/m} C^{n/m}$. In the latter case, n/m was assumed to be much less than unity; however, Low and Black (1950) reported an n/m value of 0.388 which is hardly "much less than unity" as the authors state. Unfortunately, none of the rate constants were evaluated by Kuo and Lotse.

Kuo and Lotse (1972) also studied the time-dependent adsorption of phosphate by $CaCO_3$ and Ca-kaolinite. The basic rate expression obtained by them was derived from a simple Langmuir adsorption model and was

$$\frac{dx}{dt} = k_1(C_o - x)(M - x) - k_{-1} x \qquad [6\text{-}33]$$

where x is the amount of phosphate adsorbed by the soil, C_o is the initial concentration of phosphate, M is equal to the amount of phosphate required to form a monolayer on the soil surface, and k_1 and k_{-1} are forward and reverse rate constants, respectively. Integration of Eq. (6-33) yields,

$$\ln \left(\frac{x - A - B}{x - A + B} \right) = 2Ak_1t + \ln \left(\frac{B + A}{B - A} \right) \qquad [6\text{-}34]$$

where $A = [1/4(C_o + M + \frac{k - 1}{k_1})^2 - C_oM]^{1/2}$

and

$$B = 1/2 \left(C_o + M + \frac{k_{-1} \;\; 1}{k_1}\right)$$

Only one of two possible solutions for k_1 was evaluated by the authors (none was given for k_{-1}), and their results are presented in Table 6-7. It should be noted that k_1 is a mixed second order rate constant.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

Table 6-7. Rate constants of phosphate adsorption by $CaCO_3$ and Ca-kaolinite.

Initial P concentration	k_1	
	$CaCO_3$	Ca-kaolinite
ppm	1/ppm second	1/ppm hour
0	0.12	
1	0.086	
2	0.070	
4	0.043	0.0058
12		0.0095
20		0.0017

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
1/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Based on a three-site Langmuir-type adsorption equation, McLaughlin et al. (1977) developed a time-dependent adsorption equation for phosphate on hydrous ferric oxide gel. Their equation was as follows:

$$P_T = cV + b_{I(initial)} + \Delta b_I + \frac{b_{II}\ K_{IIC}}{1 + K_{IIC}} + \frac{b_{III}\ K_{IIIC}}{1 + K_{IIIC}} \qquad [6\text{-}35]$$

where

P_T = amount of phosphate added

C = solution concentration of phosphate

V = volume of solution

$b_{I(initial)}$ = adsorption capacity for phosphate in region I of the isotherm.

Δb_I = change in adsorption maximum for region I

b_{II}, b_{III} = adsorption capacities for phosphate in regions II and III.

K_{II}, K_{III} = constants related to energies of adsorption in regions II and III.

From previous work, the authors had shown that adsorption in regions II and III was essentially complete after 17 hours. By measuring changes in the adsorption maximum b_I in region I (in a separate experiment by maintaining solution concentrations below 0.16 μg P/ml) as a function of time, a plot of b_I (= $b_{I(initial)} + \Delta b_I$) versus time allowed the authors to compute C (by numerical methods) at any time t.

It is not surprising that the authors obtain good fits to their time-dependent data since the constants b_{II}, b_{III}, K_{II}, K_{III}, and $b_{I(initial)}$ used in the model are estimated from statistical "fits" to Langmuir plots of the adsorption data. The quantity C is therefore merely a back-calculation using the same data. In addition, this expression gives no kinetic information; i.e., no rate constants were included in the expression. It seems likely that this model has little value in terms of predicting the type and magnitude of phosphate adsorption mechanisms.

A simple first-order rate expression was used by Chen et al. (1973a) to determine rate constants for adsorption of phosphate by α-Al_2O_3 and kaolinite. Their rate law

$$\frac{dP}{dt} = -K_{obs}\,(P) \qquad [6\text{-}36]$$

where, k_{obs} = observed rate constant, (P) = solution concentration of phosphate, was limited to the slow disappearance of phosphate from solution which occurred for times greater than two days. A new mineral phase was found by electron microscopy which contained Al^{3+} and phosphate. In addition, K_{obs} increased with decreasing pH, which indicated that the observed slow reaction was a result of dissolution of the mineral structures with subsequent precipitation of the aluminum phosphate mineral. Values for K_{obs} are presented in Table 6-8. Enfield et al. (1976) compared the ability of five functions to describe the kinetics of phosphate sorption during steady water flow in packed soil columns.

The kinetic functions tested were as follows:

1). A first-order Eq. (6-37) using a linear adsorption isotherm previously used by Lapidus and Amundson (1952),

$$\frac{\partial S}{\partial t} = \alpha(\kappa S - C) \qquad [6\text{-}37]$$

where, S = amount phosphate adsorbed, C = solution phosphate concentration, α = adsorption rate coefficient of phosphate, and κ = linear adsorption partition coefficient.

This equation assumes that the α is independent of S and that κ is a single-valued constant descriptive of a linear relation between S and C.

2). Later workers (Hornsby and Davidson, 1975) used the function

$$\frac{\partial S}{\partial t} = \beta(mC^n - S) \qquad [6\text{-}38]$$

where, β, and m are constants analogous to those in Eq. (6-37), and n is a constant which allows for non-linearity between S and C.

3). An emperical function formulated by Enfield (1975) was given as

$$\frac{\partial S}{\partial t} = aC^bS^d \qquad [6\text{-}39]$$

where, a, b, d are constants.

The last two of the five functions were inserted into a model in which the rate of increase of phosphate in a soil particle (S_{avg}) was limited to diffusion of the phosphate through the spherical soil particle (Skopp and Warrick, 1974),

$$S_{avg} = F(C) - \frac{6\,F(C)}{\pi^2} \sum_{j-1} \frac{1}{j^2} \exp\left(-\kappa j^2 \pi^2 t/r^2\right) \qquad [6\text{-}40]$$

where, r = radius of the soil particle, κ = diffusion coefficient of phosphate through the particle, F(C) = adsorption function relating S and C, and S_{avg} = average phosphate concentration in the soil particle.

Table 6-8. Observed rate constants for the disappearance of phosphate from solutions in the presence of kaolinite and α - Al_2O_3 at 25°C.

pH of suspension	K_{obs} (day^{-1})	
	Kaolinite	α - Al_2O_3
3.5	0.0560	0.0240
4.3	--	0.0219
4.6	0.0224	--
5.3	0.0110	--
6.0	--	0.0071
6.2	0.0030	--

Initial phosphate in the particle was assumed to be zero and concentration of phosphate at the surface of the particle is constant.

Both Freundlich and Langmuir-type functions were used for F(C); that is, the Freundlich equation

4). $F(C) = a_1 C^{b1}$ [6-41]

where a, and b_1 are constants, and the Langmuir equation

5). $F(C) = \frac{S_{max} kC}{1} + kC$ [6-42]

where, S_{max} = amount of phosphate required to complete a monomolecular on solid soil surfaces, k = a constant related to the binding energy of phosphate to the solid surfaces.

Phosphate adsorption kinetic data was obtained from twenty-five soils, and regression coefficients were obtained for each of the models presented above. Using these regression coefficients in the integrated rate expressions, the authors compared calculated and observed amounts of phosphate adsorbed at each measurement time. These correlations showed that the expressions using Eq. (6-40) predicted the experimental data in one more consistently than the other expressions.

Attempts at correlating the regression coefficients obtained from the above treatments with soil chemical and physical properties were unsuccessful. Single and multiple regressions analyses were used.

Overman and Chu (1977a, b, and c) presented a kinetic model derived from a reaction sequence

$$P + S \underset{k_d}{\overset{k_a}{\rightleftharpoons}} A \xrightarrow{k_r} F + S. \qquad [6\text{-}44]$$

where, P = concentration of phosphate in solution, S = concentration of adsorptive sites in the soil, A = concentration of adsorbed phosphate, F = concentration of fixed phosphate, k_a = rate coefficient for adsorption, k_d = rate coefficient for desorption, and k_r = rate coefficient for reaction.

For steady-state conditions in which $\frac{dP}{dt} = 0$, a mathematical treatment produced the rate expression

$$r = \frac{r_m P_s}{K+P_s} g \qquad [6\text{-}45]$$

where, r = rate of constant addition of phosphate to the batch reactor, rm = k_r S_o, where S_o = concentration of adsorptive sites on the soil with no phosphate adsorption, k_r = as defined above, P_s = steady-state solution concentration of phosphate, and $K = \frac{k_d + k_r}{k_a}$

When corrections were made for solution pH (which affected the distribution of phosphate species), the rate expressions closely described the adsorption reaction for Lakeland fine sand. Since only one soil was used in that study, correlation with soil chemical properties was not made.

The reaction scheme upon which the study was based is similar to the one outlined by Chen et al. (1973) in which the phosphate in solution comes to a rapid equilibrium and subsequently undergoes a slow reaction to a precipitated phosphate compound.

A semi-empirical approach to the kinetics of phosphate sorption-desorption was outlined by Barrow and Shaw (1975). By considering a phosphate-soil system which contained three compartments A, B, and C, and allowing them to react according to

$$A \rightleftharpoons B \rightleftharpoons C,$$

they derived an expression which accounted for 99% of the variation in solution phosphate concentrations for Australian soils.

According to their derivation, the rate of phosphate transfer from B to C is given by

$$\frac{d\alpha}{dt} = k(1 - \alpha)^n \qquad [6\text{-}46]$$

where, α = proportion of phosphate transferred from B to C, n = a constant, k = reaction rate, and t = time.

Integration and simplification of Eq. (6-46) gave

$$1 - \alpha = (kt/b_1)^{-b_1} \qquad [6\text{-}47]$$

where, $b_1 = 1/(n - 1)$, and $(n - 1)\, kt \gg 1$.

The relationship between Compartments A and B had been found previously (Barrow, 1973) to follow the Freundlich equation

$$C_t = a x_t^{b_2} \qquad [6\text{-}48]$$

where the terms have meanings as described for Eq. (6-41). Temperature effects on the rate of reactions were described by the Arrhenius equation

$$K = Ae^{-E/RT} \qquad [6\text{-}49]$$

where, k = rate constant, A = frequency factor, E = activation energy associated with the reaction where the rate is described by k, and R,T = gas constant and temperature.

Combination of Eqs. (6-47), (6-48), and (6-49) and simplification yields,

$$\ln x_t = K + B_1 \ln P - B_2 \ln t + B_3/T + \ldots \qquad [6\text{-}50]$$

where, $K = (1/b_2)\ \ln\ (m/a) - (b_1/b_2)\ \ln\ (A/b_1)$, $B_1 = 1/b_2$, $B_2 = b_1/b_2$, $B_3 = b_1\ (E/b_2)R$, and m = proportionality constant if the amount of phosphate initially adsorbed was proportional to the phosphate added, and P = concentration of phosphate added to the soil. It is of interest to consider that a, b_2, b_1, m, and E are all parameters which have values determined by a particular set of properties associated with a given soil. The values of K and B_3 could thus be calculated from a suitable set of measurements. Unfortunately, Eq. (6-50) was used only as a regression equation in the author's studies. In addition to the lack of computation of the regression parameters from independent measurements, the rate constant appears to describe only the adsorption reaction rather than desorption. The equation was successful, however, in describing the effects of time, temperature, and added phosphate upon the phosphate remaining in solution. Results obtained from several soils are listed in Table 6-9. Of the models reviewed, the one proposed by Barrow and Shaw appears to be the most satisfactory in describing phosphate sorption. Their approach encompasses several experimental variables such as 1) incubation times of added phosphate with the soil, 2) temperature of incubation, and 3) phosphate already present in the soil in addition to the times during which adsorption and desorption occur.

MECHANISMS OF PHOSPHATE SORPTION

The failure of various types of single-site adsorption equations (i.e., Langmuir) to describe phosphate retention by various soil and soil components has been generally assumed to arise from the involvement of more than one mechanism and/or adsorption site (Muljadi et al., 1966; Syers et al., 1973; Rajan et al., 1974). The complex nature of whole soils has led to the use of relatively simple systems such as the "pure" hydrous oxides and oxides of aluminum and iron and silicate clay minerals to model the sorption process of soils. Consequently, numerous investigators have tried to elucidate the mechanisms involved in phosphate sorption by hydrous metal oxides and silicate clay minerals (Chakravarti and Talibudeen 1962; Muljadi et al., 1966; Parfitt et al., 1977; Hingston et al., 1972; Chen et al., 1973b; Rajan, 1975).

The terms adsorption, desorption, "sorption," and precipitation used in discussing reaction mechanisms of phosphate and soil components are often times used interchangeably but should be delineated as follows: A sorption reaction involves the removal of phosphate from solution by its concentration in a solid phase. This may be physical sorption, which is reversible and results in a small decrease in energy; or it may be chemisorption, which is partly or completely irreversible and results in a large decrease in energy. Precipitation is the removal of two or more components from a solution by their mutual combination into a new solid-phase compound. As stated earlier

Table 6-9. Values obtained when Eq. (3-50)* was fitted to the changes in concentration of phosphate when soils were incubated at a range of temperatures.

Soil no.	Proportion of variation acc. for	No. of obs.	Coefficients of Eq. (3-50)				Equivalent values of primary coefficients		
			K	B_1	B_2	B_3	b_1	b_2	E, cal/mole
1	0.992	12	-36.4	2.51	0.676	5465	0.269	0.391	16070
4	0.985	12	-41.3	2.69	0.655	6610	0.243	0.371	20060
5	0.997	12	-37.1	2.45	0.687	5940	0.280	0.407	17160
6	0.987	48	-42.2	2.85	0.704	6673	0.247	0.351	18820
7	0.986	12	-34.3	2.52	0.647	5463	0.270	0.397	16780
9	0.982	12	-39.2	2.55	0.872	7105	0.342	0.342	16190
11	0.994	12	-39.6	2.22	0.742	7078	0.273	0.367	18940
13	0.990	84	-35.4	2.45	0.600	6551	0.245	0.408	21680
16	0.990	11	-32.4	2.93	0.604	5556	0.206	0.340	18290

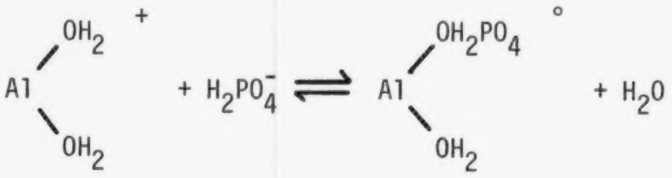
*Eq. (3-50): $\ln x_1 = K + B_1 \ln P - B_2 \ln t + B_3/T$ where x_1 is the solution concentration of phosphate is the concentration of phosphate added, t is time in days and T°K is the temperature.

there is a fine line between precipitation and chemisorption and this has been discussed in the literature (Wild, 1950; Hsu, 1964; Larsen, 1967).

The term chemical sorption will be used to include both adsorption of phosphate through surface ligand exchange and adsorption by incorporation of phosphate into the clay structure. Research to elucidate the mechanisms of phosphate retention by soils is hindered by the complex nature of the many different soil components, therefore much of the work has been performed on individual clay minerals, metal oxides and hydroxides. The exact physical and chemical characteristics of naturally occurring hydrous oxides of Fe and Al is still being researched and presents some problems in the interpretation of synthetically prepared materials.

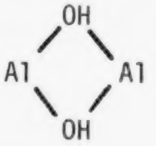
Iron and Aluminum Oxides

Many studies have shown the removal of orthophosphate from solution by solid Al and Fe hydrous oxides (Wild, 1950). The amount of phosphate sorbed in these reactions varies with the temperature, the time of reaction, and the phosphate concentration and pH of the solution. An important electrochemical property of these oxides is the influence of the solution pH on their surface charge. In acid and neutral solutions the oxides carry a net positive charge with positive and neutral sites on their surface. Recent studies of surface charge and ligand exchange (Rajan et al., 1974; Rajan, 1976) at constant pH, using hydrous alumina, have indicated that monovalent phosphate is adsorbed on positive sites displacing water that was coordinated to the oxide surface, with neutralization of the positive charge Eq. (6-51),

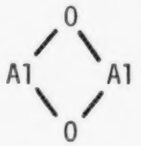


$$\left[\mathrm{Al}(OH_2)(OH_2)\right]^{+} + H_2PO_4^{-} \rightleftharpoons \left[\mathrm{Al}(OH_2PO_4)(OH_2)\right]^{\circ} + H_2O \qquad [6\text{-}51]$$

Hydrous aluminum oxide has a structure in which aluminum atoms are linked by hydroxide or oxide bridges (Hemand Roberson, 1967; Hsu, 1968).



hydroxide

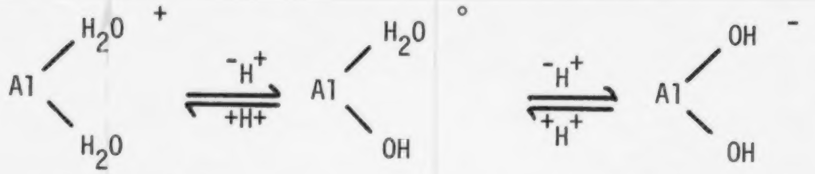


oxide

[6-52]

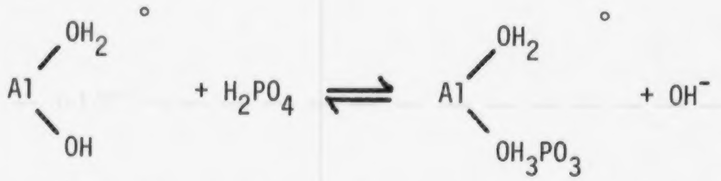
At the surface of the polymeric structure the coordinate positions of the terminal atoms are occupied by aquo Al-H_2O, and hydroxo Al-OH groups. The relative proportion of the aquo and hydroxo groups is determined by the suspension pH and in turn determines the surface charge:

TYPING GUIDE SHEET



[6-53]

(Parks, 1965). Specific adsorption of phosphate can occur by ligand exchange with aquo, hydroxo, or ol groups. In acid solution the reactivity of these groups to ligand exchange is in the order aquo $\geq$ hydroxo > ol (Thomas and Kremer, 1935; Graham and Thomas, 1947). Ligand exchange of phosphate with aquo groups would add negative charge to the surface but would not increase the concentration of the hydroxl ions in the solution (Eq. 6-51). In contrast the exchange of phosphate with hydroxo groups would not affect the surface charge, but would release equivalent amounts of hydroxyl ions into the solution (Eq. 6-54).

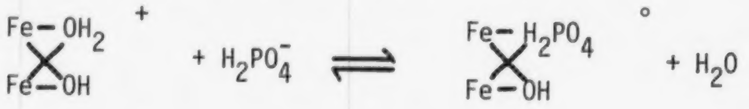


[6-54]

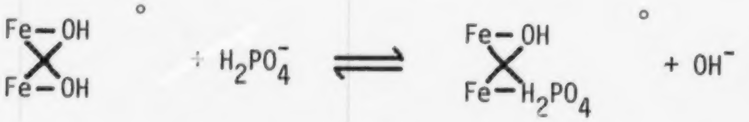
When the adsorption sites on the surface are saturated the hydrous oxide carries no net change. Additional adsorption evidently occurs by the disruption of hydrous oxide polymers into smaller units with a comcomintant increase in adsorption sites. Adsorption of phosphate on this new surface has been found to make the surface negative (Rajan et al., 1974).

Several studies have indicated that short-range order (amorphous) hydrous ferric oxide (Fe gel) like their aluminum analogs play an important role in the sorption of inorganic phosphate by soils (Williams et al., 1958; Saunders, 1965; Syers et al., 1977) and sediments (Mortimer, 1941; Syers et al., 1973).

Much of the indirect experimental evidence dealing with the fixation of phosphate by iron oxides supports the idea of coordination of Fe^{3+} to phosphate ions (Atkinson et al., 1972; Hingston et al., 1967). The initial reaction of phosphate with hydrous oxides of iron, like their aluminum counterparts, can be described by Eq. (6-55) and (6-56) depending on the degree of protonation of single co-ordinated-OH groups.



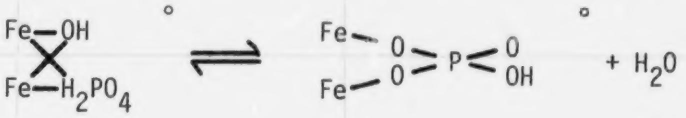
[6-55]



[6-56]

EPA-287 (Cin)
(4-78)

Russel et al. (1974) and Parfitt et al. (1975) have demonstrated that in Fe gel samples, dried prior to P sorption studies, the mechanism of retention was the formation of a binuclear co-ordinated complex at the surface of the gel. Other workers (Ryden et al., 1977) have made this same postulate and envision a condensation reaction to proceed as shown in Eq. (6-57),



[6-57]

Aluminum Silicates

The principal types of crystalline aluminum silicates are kaolinitic (1:1) and montmorillonitic (2:1) clays. It has been known for some time that there are two principle types of reactions involved in phosphate retention by aluminum silicates. At low concentrations ($< 0.3 \times 10^{-3}\underline{M}$) of phosphate, which most likely corresponds to less than full coverage of the fast reaction sites, phosphate is adsorbed by these clays on aluminum atoms situated at the edge face of crystals (Muljadi et al., 1966; Rajan and Fox, 1975). At higher phosphate concentrations exceeding the complete coverage of fast reaction sites there is evidence that sorption by displacing clay structural silicate occurs (Low and Black, 1947, and 1950; Refenberg and Buckwold, 1954; Rajan, 1975). The reaction mechanisms for sorption by clay minerals are probably similar to those for sorption by oxyhydroxide compounds of Fe and Al.

Miscellaneous Soil Components

Calcium carbonate may be present in alkaline and some neutral soils and subsequently may influence the sorption of phosphate in these soils. Literature values for the sorption capacity of calcium carbonate are between that of crystalline clay minerals and hydrous oxides of iron and aluminum (Holford, 1974; Kuo and Lotse, 1972). Phosphate retention on calcium carbonate is initially a rapid mono-layer sorption and this may be followed by precipitation of $CaHPO_4$ at higher phosphate concentrations (Cole et al., 1953; Griffin and Jurinak, 1973).

THERMODYNAMICS OF PHOSPHATE SORPTION PROCESSES

Several authors have used thermodynamic treatments to assist in characterizing phosphate sorption. Two thermodynamic quantities discussed have been the enthalpy of adsorption and the free energy change upon adsorption of the phosphate entity. Each of these quantities can be obtained for certain welldefined systems and have important restrictions placed upon them in the derivations of their associated relationships. The following treatment was adapted from Denbigh (1971).

Consider a vessel which contains a solid adsorbent, aqueous solution of $H_2PO_4^-$, and supporting inert electrolyte. The content of water is such that its mole fraction is constant throughout any adsorption process. The thermodynamic system will consist only of the phosphate species, associated cations, and the adsorbent with its associated anions. The process under consideration is the reversible transfer of the phosphate species from solution to the solid phase. At equilibrium,

$$\Sigma\ \nu_i \mu_i = 0 \qquad [6\text{-}58]$$

where, ν_i = stoichiometric coefficient, μ_i = chemical potential of species i. The chemical potential μ_i is defined as

$$\left(\frac{\partial G}{\partial n_i}\right)_{T,P,n_{j\neq i}} \equiv \mu_i \qquad [6\text{-}59]$$

where G is the Gibbs free energy and n_j is the mole number of each component other than the i-th one.

It is commonly assumed that the system undergoes a reversible process

$$H_2PO_4^- + A^-[\text{Solid}] \rightleftarrows H_2PO_4[\text{Solid}] + A^-. \qquad [6\text{-}60]$$

A change in the free energy occurs during the process such that

$$\Delta G° = RT\ln K \qquad [6\text{-}61]$$

where, $K = \Pi(\gamma_i m_i)^{\nu_i}$ and γ_i = activity coefficient for species i, m_i = concentration of i on a molar scale. Now,

$$\Delta G° = \Sigma \nu_i \mu_i° \qquad [6\text{-}62]$$

and $\mu_i°$ = chemical potential of species i when $\gamma_i m_i = 1$ and is a function only of temperature and pressure. In order to calculate $\Delta G°$, activity coefficients of all species as well as the stoichiometry of the reaction must be known. We know of no strict derivation of this relation [Eq. (6-61)] for reactions on solid surfaces. Usually, the stoichiometry is based on weight of phosphate adsorbed per weight of soil (Bache, 1964; Ryden et al. 1977).

Another thermodynamic quantity used in describing phosphate adsorption is the temperature dependence of K. This quantity can be derived from Eqs. (6-61) and (6-62),

$$-RT\ln K = \Sigma \nu_i \mu_i°$$

Rearrangement and differentiation gives the van't Hoff equation

$$\frac{d\ln K}{dT} = \frac{\Delta H°}{RT^2} \qquad [6\text{-}63]$$

where, $\Delta H°$ = enthalpy of reaction when reactants are in their standard states. In this case, $\Delta H° = \tilde{H}°_A + \tilde{H}_{H_2PO_4[\text{Solid}]} - \tilde{H}_{H_2PO_4^-} - \tilde{H}_{A[\text{Solid}]}$, where ~ represents a partial molar quantity of the species in (6-60). The same assumptions apply to the use of (6-63) as in the use of (6-61). $\tilde{H}°$ and $\tilde{H}$ must be known for each respective species. Low and Black used the van't Hoff expression to compute ΔH° for the adsorption of phosphate by kaolinite. The value of calculating such a thermodynamic property from this type of system has been useful only on a relative basis. The observation that phosphate sorption increases with temperature has been explained by several authors as a result of positive ΔH° (endothermic) values (Low and Black, 1950; Haseman et al., 1950). However, other authors (Barrow and Shaw, 1975) have noted that less phosphate is adsorbed at higher temperatures (at equal solution concentrations). Differences in these observations would appear to result from non-equilibrium conditions at the time of measurement and a change in the rate of sorption-desorption reactions with temperature rather than the occurrence of an endothermic adsorption process.

In addition to this limitation, (6-63) applies only to reversible processes. Lack of proof of reversibility is common to all studies reviewed.

This review has focused on the quantification of the inorganic phosphate sorption-desorption processes in soil-water systems. There appears to be a general agreement in the literature that the disappearance of phosphate from soil solution results from a fast initial sorption reaction followed by a much slower transformation of phosphate to crystalline precipitates. The mechanisms of these transformations have not been elucidated to date. Kinetics of the transformations have only been determined at a phenomenological level rather than from a mechnistic process-oriented standpoint. Hence, an important part of the information required for determining a phosphate partition function is absent.

The following conclusions can be drawn based on our review of the phosphate sorption literature.

1. A universal partition function cannot be developed for soils using literature data. Variations in measurement of the "active" Fe and Al, and time-dependence of phosphate sorption appear to be the two most significant parameters in a phosphate partition function. These parameters have not been reported adequately in the literature for use in a partition function.

2. "Active" Fe and Al appear to be measured quantitatively by oxalate extraction rather than by citrate-dithionite-bicarbonate extraction. Crystallinity of Fe and Al oxyhydroxides appears to be a dominant factor determining phosphate sorption.

3. Time-dependent disappearance of phosphate during sorption and reappearance during desorption has not been fully explained and has been modeled successfully by the procedure of Barrow and Shaw (1975).

4. A broad range of Langmuir sorption parameters was found for phosphate sorption by soils and other solid sorbents. Based on a limited amount of data, the sorption parameters were found to be significantly correlated with oxalate-extractable Fe and Al.

5. Lack of uniformity in experimental methods used in determining the Langmuir sorption parameters was noted. Development of standardized methodology (protocols) for this purpose appears essential for quantification of appropriate sorption parameters.

The following recommendations are made based on this review:

1. Further testing of phosphate sorption models is required to determine the most suitable sorption parameter.

2. Standardized methodology (protocols needs to be developed for measurement of sorption parameters, "active" species involved in phosphate sorption, and the time-dependence of sorption and desorption.

3. Quantification of a "crystallinity" index for Fe and Al oxyhydroxides in soils is essential in describing phosphate sorption.

4. The final result must be a partition function which describes the relative concentrations of phosphate in solid and solution phases. The function should include the variables of Fe and Al content of the soil (and any other chemical properties that might be required), times of the sorption-desorption processes, and the suitable sorption parameters.

REFERENCES FOR SECTION 6

Adamson, A. W. 1976. Physical Chemistry of Surfaces. John Wiley and Sons, NY. Third edition. Chapter 14.

Aiba, S., and H. Ohtake. 1977. Simulation of PO_4-P balance in a shallow and polluted river. Water Res. 11:159-164.

Alston, A. M., and K. W. Chin. 1974. Rock phosphate and superphosphate as sources of phosphorus for subterranean clover on an acid sandy soil. Aust. J. Exp. Agric. Anim. Husb. 14:358-361.

Amer, F., D. R. Bouldin, C. A. Black, and F. R. Duke. 1955. Characterization of soil phosphorus by anion exchange resin adsorption and P^{32}-equilibration. Plant Soil 6:391-408.

Arambarri, P., and O. Talibudeen. 1959. Factors influencing the isotopically exchangeable phosphate in soils. Plant Soil 11:343-354.

Atkinson, R. J., F. J. Hingston, A. M. Posner, and J. P. Quirk. 1970. Elovich equation reactions at solid-liquid interfaces. Nature 226:148-149.

Atkinson, R. J., P. M. Posner, and J. P. Quirk. 1972. Kinetics of isotopic exchange of phosphate at the α-FeOOH (goethite)-aqueous solution interface. J. Inorg. Nucl. Chem. 34:2201-2211.

Avnimelech, Y. 1968. Analysis of P^{32} and Ca^{45} Exchange Between Hydroxyapatite and its Equilibrium Solution. Israel J. Chem. 6:375-385.

Bache, B. W. 1964. Aluminum and iron phosphate studies relating to soils 11. Reactions between phosphate and hydrous oxides. J. Soil Sci. 15:110-116.

Bache, B. W., and E. G. Williams. 1971. A phosphate sorption index of soils. J. Soil Sci. 22:289-301.

Ballaux, J. C., and D. E. Peaslee. 1975. Relationships between sorption and desorption of phosphorus by soils. Soil Sci. Soc. Am. Proc. 39:275-278.

Barber, S. A. 1977. Application of Phosphate Fertilizers: Methods, Rates and Time of Application in Relation to the Phosphorus Status of Soils. Phosphorus Agric. 70:109-115.

Barone, J. P., and G. H. Nancollas. 1977. The seeded growth of calcium phosphates: The effect of soil/solution ratio in controlling the nature of the growth phase. J. Colloid Interface Sci. 62:421-431.

Barrow, N. J. 1972. Influence of solution concentration of calcium on the adsorption of phosphate, sulfate, and molybdate by soils. Soil Sci. 113:175-180.

Barrow, N. J. 1973. Relationship between a soil's ability to adsorb phosphate and the residual effectiveness of superphosphate. Aust. J. Soil Res. 11:57-63.

Barrow, N. J. 1974. On the displacement of adsorbed anions from soil: 1. Displacement of molybdate by phosphate and by hydroxide. Soil Sci. 116:423-431.

Barrow, N. J. 1974. On the displacement of adsorbed anions from soil: 2. Displacement of phosphate by arsenate. Soil Sci. 117:28-33.

Barrow, N. J. 1974. The slow reactions between soil and anions. 1. Effects of time, temperature, and water content of a soil on the decrease in effectiveness of phosphate for plant growth. Soil Sci. 118:380-386.

Barrow, N. J. 1974. Effect of previous additions of phosphate on phosphate adsorption by soils. Soil Sci. 118:82-89.

Barrow, N. J. 1975. Chemical form of inorganic phosphate in sheep faeces. Aust. J. Soil Res. 13:63-67.

Barrow, N. J. 1975. The response to phosphate of two annual pasture species. 1. Effect of the soil's ability to adsorb phosphate on comparative phosphate requirement. Aust. J. Agric. Res. 26:137-143.

Barrow, N. J. 1977. Phosphorus uptake and utilization by tree seedlings. Aust. J. Bot. 25:571-584.

Barrow, N. J., P. G. Ozanne, and T. C. Shaw. 1967. Nutrient potential and capacity. 1. The concepts of nutrient potential and capacity and their application to soil potassium and phosphorus. Aust. J. Agric. 16:61-76.

Barrow, N. J., and T. C. Shaw. 1974. Factors affecting the long-term effectiveness of phosphate and molybdate fertilizers. Commun. Soil Sci. Plant Anal. 5:355-364.

Barrow, N. J., and T. C. Shaw. 1975. The slow reactions between soil and anions: 2. Effect of time and temperature on the decrease in phosphate concentration in the soil solution. Soil Sci. 119:167-177.

Barrow, N. J., and T. C. Shaw. 1975. The slow reactions between soil and anions. 3. The effects of time and temperature on the decrease in isotopically exchangeable phosphate. Soil Sci. 119:190-197.

Barrow, N. J., and T. C. Shaw. 1975. The slow reactions between soil and anions. 5. Effects of period of prior contact on the desorption of phosphate from soils. Soil Sci. 119:311-320.

Barrow, N. J., and T. C. Shaw. 1976. Sodium bicarbonate as an extractant for soil phosphate. 1. Separation of the factors affecting the amount of phosphate displaced from soil from those affecting secondary adsorption. Geoderma 16:91-107.

Barrow, N. J., and T. C. Shaw. 1976. Sodium bicarbonate as an extractant for soil phosphate. 2. Effect of varying the conditions of extraction on the amount of phosphate initially displaced and on the secondary adsorption. Geoderma 16:109-123.

Barrow, N. J., and T. C. Shaw. 1976. Sodium bicarbonate as an extractant for soil phosphate. 111. Effects of the buffering capacity of a soil for phosphate. Geoderma 16:273-283.

Barrow, N. J., and T. C. Shaw. 1977. Factors affecting the amount of phosphate extracted from soil by anion exchange resin. Geoderma 18:309-323.

Barrow, N. J., and T. C. Shaw. 1977. The slow reactions between soil and anions: 6. Effect of time and temperature of contact on fluoride. Soil Sci. 124:265-278.

Beckett, P. H. T., and R. E. White. 1964. Studies on the phosphate potentials of soils. III. The pool of Labile inorganic phosphate. Plant Soil 21:253-257.

Beek, J., F. A. M. de Haan, and W. H. van Riemsdijk. 1977. Phosphates in soils treated with sewage water: 1. General information on sewage farm, soil, and treatment results. J. Environ. Qual. 6:4-7.

Beek, J., F. A. M. de Haan, and W. H. van Riemsdijk. 1977. Phosphates in soils treated with sewage water: 11. Fractionation of accumulated phosphates. J. Environ. Qual. 6:7-12.

Bhavnagary, H. M., J. S. Venugopal, and S. K. Majumder. 1977. Preparation of tricalcium phosphate by hydrolysis of dicalcium phosphate with calcium hydroxide. J. Appl. Chem. Biotechnol. 27:393-398.

Biddappa, C. C. 1976. Phosphorus sorption and desorption pattern in four rice soils of Orissa. Madras Agric. J. 63:156-159.

Biddappa, C. C., and S. Patnaik. 1977. The correlation of nitrogen and phosphorus soil tests with response of paddy through modified Mitscherlich-Bray equation. Mysore J. Agric. Sci. 11:28-33.

Bjerrum, N. 1949. "Selected papers," pp. 245-248. Munksgaard, Copenhagen.

Blanchar, R. W., and D. C. Riego. 1977. Pyro- and tripoly-phosphate contents of sediments. Water Air Soil Pollut. 7:27-31.

Bowden, J. W., M. D. A. Bolland, A. M. Posner, and J. P. Quirk. 1973. Generalized model for anion and cation adsorption at oxide surfaces. Nature Phys. Sci. 245:81-83.

Bowden, J. W., A. M. Posner, and J. P. Quirk. 1973. A model for ion adsorption on variables charge surfaces. Int. Congr. Soil Sci. Trans. 10th (Moscow, Russia) 11:29-34.

Bowden, J. W., A. M. Posner, and J. P. Quirk. 1977. Ionic adsorption on variable charge mineral surfaces. Theoretical-charge development and titration curves. Austr. J. Soil Res. 15:121-136.

Boyd, G. E., A. W. Adamson, and L. S. Myers, Jr. 1947. The exchange adsorption of ions from aqueous solutions by organic zeolites: 11. Kinetics. J. Am. Chem. Soc. 69:2836-2848.

Brewster, J. L., A. N. Gancheva, and P. H. Nye. 1975. The determination of desorption isotherms for soil phosphate using low volumes of solution and an anion exchange resin. J. Soil Sci. 26:264-377.

Broyer, T. C., C. M. Johnson, and R. P. Huston. 1972. Selenium and nutrition of Astragalus: 11. Ionic sorption interactions among selenium, phosphate, and the macro- and micronutrient cations. Plant Soil 36:651-669.

Burnham, C. P. 1973. Extraction methods for aluminum and iron in relation to phosphate adsorption. Commun. Soil Sci. Plant Anal. 4:9-16.

Cabrera, F., L. Madrid, and P. DeArambarri. 1977. Adsorption of phosphate by various oxides: theoretical treatment of the adsorption envelope. J. Soil Sci. 28:306-313.

Calvert, D. V. 1975. Nitrate, phosphate, and potassium movement into drainage lines under three soil management systems. J. Environ. Qual. 4:183-186.

Chakravarti, S. N., and O. Talibudeen. 1961. Phosphate interaction with clay minerals. Soil Sci. 92:232-242.

Chen, Y. S. R., J. N. Butler, and W. Stumm. 1973a. Kinetic study of phosphate reaction with aluminum oxide and kaolinite. Environ. Sci. and Technol. 7:327-332.

Cho, C. M., J. Strong, and G. J. Racz. 1970. Convective transport of orthophosphate (P-31 and P-32) in several Manitoba soils. Can. J. Soil Sci. 50:303-315.

Cloos, P., A. Herbillon, and J. Echeverria. 1968. Allophane-like synthetic silico-aluminas: Phosphate adsorption and availability. Int. Congr. Soil Sci. Trans. 9th (Adelaide, Aust.) 11:733-743.

Cole, C. V., S. R. Olsen, and C. O. Scott. 1953. The nature of phosphate sorption by calcium carbonate. Soil Sci. Soc. Am. Proc. 17:352-356.

Cooke, I. J. 1966. A kinetic approach to the description of soil phosphate status. J. Soil Sci. 17:56-64.

Cooke, I. J., and J. Hislop. 1963. Use of anion-exchange resin for the assessment of available soil phosphate. Soil Sci. 96:308-312.

Dalal, R. C. 1974. Desorption of soil phosphate by anion-exchange resin. Commun. Soil Sci. Plant Anal. 5:531-538.

Dalal, R. C., and E. G. Hallsworth. 1977. Measurement of isotopic exchangeable soil phosphorus and interrelationship among parameters of quality, intensity, and capacity factors. Soil Sci. Soc. Am. J. 41:81-86.

Dankiewicz, J., and J. Klimek. 1978. Solid solutions of $CaSO_4 \cdot 2H_2O$ with a high degree of isomorphic substitution of phosphates into the gypsum lattice. Pol. J. Chem. 52:485-491.

Daughtrey, Z. Q., J. W. Gilliam, and E. J. Kamprath. 1973. Phosphorus supply characteristics of acid organic soils as measured by desorption and mineralization. Soil Sci. 115:18-24.

Denbigh, K. 1971. The principles of chemical equilibrium. Cambridge Univ. Press. Chapter 10.

Dick, M. A., and M. A. Tabatabai. 1977. An alkaline oxidation method for determination of total phosphorus in soils. Soil Sci. Soc. Am. J. 41:511-514.

Donigan, A. S., Jr., D. C. Beyerlein, H. H. Davis, Jr., and N. H. Crawford. 1977. Agricultural runoff management (ARM) model version II: Refinement and testing. Environmental Protection Agency Report No. EPA-600/3-77-098.

During, C. 1968. Equilibrium concentrations of inorganic phosphate and phosphate sorption properties in soils under permanent pasture: Some practical applications. Int. Congr. Soil Sci. Trans. 9th (Adelaide, Aust.) 11:281-292.

Dyanand, S., M. B. Kamath, and N. N. Goswami. 1976. Effect of lime and phosphate on the uptake and utilization of phosphorus by rice in acid laterite soils. J. Nucl. Agric. Biol. 5:61-64.

Edzwald, J. K. 1977. Phosphorus in aquatic systems: the role of the sediments. Adv. Environ. Sci. Technol. 8:183-214.

Edzwald, J. K., D. C. Toensing, M. C-Y Leung. 1976. Phosphate adsorption reactions with soil, clay minerals. Environ. Sci. Technol. 10: 485-490.

El-Nennah, M. 1975. Phosphate adsorption by Na-, Mg- and Ca-, sodium magnesium, calcium, saturated soil clays. Z. Pflanzenernahr Bodenkd 1:33-37.

El-Nennah, M., F. M. Abdou, and M. A. Massoud. 1977. The stability of sparingly soluble phosphates in alkaline soils. Phosphorus Agric. 69:29-34.

Enfield, C. G., and B. E. Bledsoe. 1975. Fate of wastewater phosphorus in soil. J. Irrig. Drain. Div. Amer. Soc. Civil Eng. 101:145-155.

Enfield, C. G., C. C. Harlin, Jr., and B. E. Bledsoe. 1976. Comparison of five kinetic models for orthophosphate reactions in mineral soils. Soil Sci. Soc. Am. J. 40:243-248.

Ericsson. Y. 1949. Enamel-apatite solubility. Investigations into the calcium phosphate equilibrium between enamel and saliva. Atta Odontol. Scand. 8, Suppl. 3.

Evans, R. L., and J. J. Jurinak. 1976. Kinetics of phosphate release from a desert soil. Soil Sci. 121:205-211.

Evans, T. D., and J. K. Syers. 1971. An application of autoradiography to study the spacial distribution of ^{33}P-labelled orthophosphate added to soil crumbs. Soil Sci. Soc. Am. Proc. 35:906-909.

Fiskell, J. G. A., and R. S. Mansell. 1975. Dependence of P sorption in a Spodosol upon P rate, contact time, and deep tillage. Soil Crop Sci. Soc. Fla. Proc. 34:34-38.

Fitter, A. H., and C. D. Sutton. 1975. The use of the Freundlich isotherm for soil phosphate sorption data. J. Soil Sci. 26:241-246.

Fokin, A. D. 1976. Studies of the transport of iron and phosphorus in a Podzolic clay loam soil and isotopic indicators. Soviet Soil Sci. 8:321-330.

Fordham, A. W. 1963. The measurement of chemical potential of phosphate in soil suspensions. Aust. J. Soil Res. 1:144-156.

Fordham, A. W., and U. Schwertman. 1977. Composition and reactions of liquid manure (gulle), with particular reference to phosphate: 1. Analytical composition and reaction with poorly crystalline iron oxide (ferrihydrite). J. Environ. Qual. 6:133-136.

Fox, R. L., and E. J. Kamprath. 1971. Adsorption and leaching of P in acid organic soils and high organic matter sand. Soil Sci. Soc. Am. Proc. 35:154-156.

Fox, R. L., and E. J. Kamprath. 1970. Phosphate Sorption Isotherms for Evaluating the Phosphate Requirements of Soil. Soil Sci. Soc. Amer. Proc. 34:902-907.

Fried, M., C. E. Hagen, J. F. Saiz Del Rio, and J. E. Legget. 1957. Kinetics of phosphate uptake in the soil-plant system. Soil Sci. 84:427-437.

Gachon, L. 1977. The usefulness of a good level of soil phosphate reserves. Phosphorus Agric. 70:25-30.

Galindo, G. G., C. Olguin, and E. B. Schalscha. 1972. Phosphate-sorption capacity of clay fractions of soils derived from volcanic ash. Geoderma 7:225-232.

Gardner, B. R., and J. P. Jones. 1973. Effects of temperature on phosphate sorption isotherms and phosphate desorption. Commun. Soil Sci. Plant Anal. 4:83-93.

Gastuche, M. C., J. J. Fripiat, and S. Sokolski. 1963. Fixation du phosphore par les hydroxydes de fer et d'aluminum amorphes et cristallises. Pedologic XIII:155-180.

Gebhardt, H., and N. T. Coleman. 1974. Anion adsorpton by allophanic tropical soils: 111. phosphate adsorption. Soil Sci. Soc. Am. Proc. 38:263-266.

Gillman, G. P. 1973. Studies of some deep sandy soils in Cape York peninsula North Queesland: 3. Losses of applied phosphorus and sulphur. Aust. J. Exp. Agr. Anim. Husb. 13:418-422.

Glidewell, C. 1977. Intramolecular non-bonded radii: Application to synthetic and naturally occurring beryllates, aluminates, silicates, germanates, phosphates, and arsenates. Inorg. Chim. Acta. 25:77-90.

Glinski, J., Z. Sokolowska, and J. Szczypa. 1976. Sorption of phosphorus and calcium in artifically flocculated soils. Pol. J. Soil Sci. 9: 11-17.

Gorlach, E., K. Gorlach, and A. Compala. 1969. The effect of phosphates on the sorption and desorption of molybdates in the soil. Agrichimica 13:506-512.

Graham, R. P., and W. P. Thomas. 1947. Reactivity of hydrous alumina towards acids. J. Amer. Chem. Soc. 69:816-819.

Greenwald, I. 1942. The solubility of calcium phosphate. I. The effect of pH and the amount of solid phase. J. Biol. Chem. 143:703-714.

Griffin, R. A., and J. J. Jurinak. 1973. The Interaction of Phosphate with Calcite. Soil Sci. Soc. Amer. Proc. 37:847-850.

Griffin, R. A., and J. J. Jurinak. 1973. Test of a new model for the kinetics of adsorption-desorption processes. Soil Sci. Soc. Am. Proc. 37:869-872.

Griffin, K. A., and J. J. Jurinak. Kinetic of the phosphate interaction with calcite. Soil Sci. Soc. Amer. Proc. 38:75-79.

Gunary, D. 1970. A new adsorption isotherm for phosphate in soil. J. Soil Sci. 21:72-77.

Gunary, D., and C. D. Sutton. 1967. Soil factors affecting plant uptake of phosphate. J. Soil Sci. 18:167-173.

Gupta, R. K., and T. A. Singh. 1977. Interrelationships among labile phosphorus kinetics phosphate potentials and fertilizer response of rice in Sub-Himalayan soil. Agrochimica 21:123-133.

Hagin, J., E. Segall, and Y. Avnimelech. 1971. Fixation and availability of added phosphorus in soils as a function of bulk movement and diffusion and the rate of formation of reaction products. Technion-Israel Institute of Technology, Fertilizer Development and Soil Fertility Laboratory, final report.

Harrop, D., and A. J. Head. 1977. Termodynamic properties of phosphorus compounds. 4. The energy of combustion of triphenylphosphine oxide: a test substance for the combustion calorimetry of organophosphorus compounds. J. Chem. Thermodyn. 9:1067-1076.

Harter, R. D. 1969. Phosphorus adsorption sites in soils. Soil Sci. Soc. Am. Proc. 33:630-632.

Harter, R. D., and B. B. Foster. 1976. Computer simulation of phosphorus movement through soils. Soil Sci. Soc. Am. J. 40:239-242.

Haseman, J. F., E. H. Brown, and C. D. Whitt. 1950. Some reactions of phosphate with clays and hydrous oxides of iron and aluminum. Soil Sci. 70:257-271.

Haysom, M. B. C. 1974. Phosphate sorption characteristics of Mackay soils. Proc. Queensl. Soc. Sugar Cane Technol. 41st:43-51.

Helyar, K. R., and D. N. Munns. 1975. Phosphate fluxes in the soil-plant system: A computer simulation. Hilgardia 43:103-130.

Helyar, K. R., D. N. Munns, and R. G. Buran. 1976. Adsorption of phosphate by gibbsite: 11. Formation of a surface complex involving divalent cations. J. Soil Sci. 27:315-323.

Hem, J. D., and C. E. Robertson. 1967. Form and stability of aluminum hydroxide complexes in dilute solution, U. S. Geol. Survey Water Supply Paper, 1827-A.

Hemwell, J. B. 1957. The tole of clay minerals in phosphorus fixation. Soil Sci. 83:101-108.

Hernando, V. 1977. The problem of phosphorus in spanish calcareous soils. Phosphorus Agric. 70:47-62.

Hill, W. A., H. L. Bohn, and G. V. Johnson. 1974. White phosphorus-ammonia reaction product as a phosphatic fertilizer in alkaline and limed acid soils. Agron. J. 66:115-117.

Hira, G. S., and N. T. Singh. 1977. Observed and predicted rates of phosphorus diffusion in soils of varying bulk density and water content. Soil Sci. Soc. Am. J. 41:537-540.

Hingston, F. J., R. J. Atkinson, P. M. Posner, and J. P. Quirk, 1967. Specific adsorption of anions. Nature (Lond.) 215:1459-1461.

Hingston, F. J., A. M. Posner, and J. P. Quirk. 1971. Competitive adsorption of negatively charged ligonds on oxide surfaces. I. Surface Chemistry of Oxides. Disc. Faraday Society. 52:334-342.

Holford, I. C. R. 1974. In: Fertilizers and the Environment. D.R. Leece (Ed.) Purt. Inct. Agri. Sci.

Holford, I. C. R. 1977. Soil properties related to phosphate buffering in calcareous soils. Commun. Soil Sci. Plant Anal. 8:125-137.

Holford, I. C. R., and G. E. G. Mattingly. 1975. Phosphate sorption by Jurassic oolitic limestones calcareous soils. Geoderma 13:257-264.

Table A31. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Terbacil and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
EUSTIS	42	5.6	0.56	5.2	1.2000E-01	0.1200	0.88	2.1429E+01
CECIL LS	10	5.8	0.40	.	1.5000E-01	0.1500	0.96	3.7500E+01
CECIL	42	5.6	0.90	6.8	3.8000E-01	0.3800	0.99	4.2222E+01
WEBSTER	42	7.3	3.87	54.7	2.4600E+00	2.4600	0.88	6.3566E+01
KEYPORT SIL	10	5.4	1.21	.	1.7000E+00	1.7000	0.50	1.4050E+02

Table A32. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Thimet and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
HUGO GRAVELLY SL	15	5.5	0.12	.	1.9600E+00	1.9600	0.93	1.6333E+03
SWEENEY SCL	15	6.3	1.65	.	1.3710E+01	13.7100	1.01	2.1092E+03
ELKHORN SL	15	6.0	0.09	.	3.9400E+00	3.9400	0.94	4.5814E+03
TIERRA CL	15	6.2	0.33	.	1.5500E+01	15.5000	1.00	4.6970E+03

Holford, I. C. R., and G. E. G. Mattingly. 1976. Soil phosphate adsorption and plant availability of phosphate. Plant Soil 44:377-389.

Holford, I. C. R., R. W. M. Wedderburn, and G. E. G. Mattingly. 1974. A Langmuir two-surface equation as a model for phosphate adsorption by soils. J. Soil Sci. 25:242-255.

Hope, G. D., and J. K. Syers. 1976. Effects of solution: soil ratio on phosphate sorption by soils. J. Soil Sci. 27:301-306.

Hornsby, A. G., and J. M. Davidson. 1973. Solution and adsorbed fluometuron concentration distribution in a water-saturated soil: Experimental and predicted evaluation. Soil Sci. Soc. Amer. Proc. 37:823-828.

Hsu, P. H. 1964. Adsorption of phosphate by aluminum and iron in soils. Soil Sci. Soc. Am. Proc. 28:474-478.

Hsu, P. H. 1965. Fixation of phosphate by aluminum and iron in acid soils. Soil Sci. 99:398-402.

Hsu, P. H. 1976. Comparison of iron(III) and aluminum in precipitation of phosphate from solution. Water Res. 10:903-907.

Hsu, P. H., and D. A. Rennie. 1962. Reactions of phosphate in aluminum systems. 1. Adsorption of phosphate by X-ray amorphous "aluminum hydroxide." Can. J. Soil Sci. 42:197-209.

Huang, C. P. 1977. Removal of phosphate by powdered aluminum oxide adsorption. J. Water Pollut. Control Fed. 49:1811-1817.

Huffman, E. O. 1969. Behavior of fertilizer phosphates. Trans. Int. Congr. Soil Sci., 9th. 2:745-754.

Huffman, E. O. 1970. Fertilizer-soil reactions and the phosphate status of soils. Phosphorus Agric. 24:13-23.

Humphreys, F. R., and W. L. Pritchett. 1971. Phosphorus adsorption and movement in some sandy forest soils. Soil Sci. Soc. Am. Proc. 35:495-500.

Hwang, C. P., T. H. Leckie, and P. M. Huang. 1972. Adsorption of inorganic phosphorus by lake sediments. J. Water Pollut. Control Fed. 48:2754-2760.

Irving, R. J., M. H. Abraham, J. E. Salmon, A. Marton, and J. Inczedy. 1977. Thermochemical aspects of anion exchange reactions. 1. Exchange reactions involving chloride, hydroxide, and orthophosphate ions. J. Inorg. Nucl. Chem. 39:1433-1436.

Jain, J. M., M. Velayutham, and R. Hasan. 1972. Changes in the dynamics of phosphate equilibria on storing soil samples. Curr. Sci. 41:489-490.

Jensen, H. E. 1970. Phosphate potential and phosphate capacity of soils. Plant Soil 33:17-29.

Jensen, H. E. 1971. Phosphate solubility in Danish soils equilibrated with solutions of differing phosphate concentrations. J. Soil Sci. 22:261-266.

Jones, J. P., and R. L. Fox. 1977. Phosphate sorption curves as a soil testing technique: A simplified approach. Commun. Soil Sci. Plant Anal. 8:209-219.

John, M. K. 1972. Factors affecting the adsorption of micro-amounts of tagged phosphorus by soils. Commun. Soil Sci. Plant Anal. 3:197-205.

Kafkafi, U., A. M. Posner, and J. P. Quirk. 1967. Desorption of phosphate from kaolinite. Soil Sci. Soc. Am. Proc. 31:347-353.

Khalid, R. A., W. H. Patrick, Jr., and R. D. Dalaune. 1977. Phosphorus sorption characteristics of flooded soils. Soil Sci. Soc. Am. J. 41:305-310.

Kinjo, T., and P. F. Pratt. 1971. Nitrate adsorption: 11. In competition with chloride, sulfate, and phosphate. Soil Sci. Soc. Am. Proc. 35:725-728.

Kittrick, J. A., and M. L. Jackson. 1957. Electron-microscope observations of the reactim of phosphate with minerals, leading to a unified theory of phosphate fixation in soils. J. Soil Sci. 7:81-89.

Krishnappa, M., C. C. Biddappa, and B. V. Venkata Rao. 1975. A kinetic approach in the study of phosphorus status of red sandy loam soils. J. Indian Soc. Soil Sci. 23:47-50.

Kunishi, H. M., and A. W. Taylor. 1975. The effect of phosphate applications on the diffusion coefficients and available phosphate in an acid soil. J. Soil Sci. 26:267-277.

Kuo, S., and E. G. Lotse. 1972. Kinetics of phosphate adsorption by calcium carbonate and Ca-kaolinite. Soil Sci. Soc. Am. Proc. 36: 725-729.

Kuo, S., and E. G. Lotse. 1973. Kinetics of phosphate adsorption and desorption by hematite and gibbsite. Soil Sci. 116:400-406.

Kyle, J. H., A. M. Posner, and J. P. Quirk. 1975. Kinetics of isotopic exchange of phosphate adsorbed on gibbsite. J. Soil Sci. 26:32-43.

Laidler, K. J. 1965. Chemical Kinetics. McGraw-Hill, NY. p. 318.

Lake, C. A., and W. G. MacIntyre. 1977. Phosphate and tripolyphosphate adsorption by clay minerals and estuarine sediments. Virginia Polytechnic Inst. Stat. Univ., Virginia Water Resources Res. Center. Bull. 109.

Lance, J. C. 1977. Phosphate removal from sewage by soil columns. J. Environ. Qual. 6:279-284.

Langmuir, I. 1918. The adsorption of gasses on plane surfaces of glass, mica, and platinum. J. Am. Chem. Soc. 40:1361-1403.

Lapidus, L., and N. R. Amundson. 1952. Mathematics of adsorption in beds. VI. The effect of longitudinal diffusion in ion exchange and chromatographic columns. J. Phys. Chem. 56:984-988.

Larsen, S. 1965. The influence of calcium chloride concentration in the determination of lime and phosphate potentials of soils. J. Soil Sci. 16:275-278.

Larsen, S. 1966. The solubility of phosphate in a calcareous soil. J. Soil Sci. 17:121-126.

Larsen, S. 1967. Soil phosphorus. Adv. Agron. 19:151-210.

Larsen, S., and M. N. Court. 1961. Soil phosphate solubility. Nature. 189:164-165.

Larsen, S., D. Gunary, and C. D. Sutton. 1965. The rate of immobilization of applied phosphate in relation to soil properties. J. Soil Sci. 16:141-148.

Larsen, S., and A. E. Widdowson. 1964. Effect of soil/solution ratio on determining the chemical potentials of phosphate ions in soil solutions. Nature 203:942.

Leaver, J. P., and E. W. Russell. 1957. The reaction between phosphate and phosphate-fixing soils. J. Soil Sci. 8:

Lee, G. F. 1970. "Entrophication Information Proyram," Occ. Pap. No. 1, University of Wisconsin, Madison.

Licthtenwalner, D. C., A. L. Flenner, and N. E. Gordon. 1922. Adsorption and replacement of plant food in colloidal oxides of iron and aluminum. Soil Sci. 15:3.

Lieser, Von K. H., Ph. Gutlich, and I. Rosenbaum. 1945. Lehrstuhl fur Kernchemie, Technische Hochschule Darmstadt. Radiochim. Acta. 4:216.

Lindsay, W. L., and Vlek, P. G. L. 1977. "Phosphate Minerals," In Minerals in Soil Environments (Ed. by J. B. Dixon and S. B. Weed), SSSA, Madison, Wisconsin.

Lindsay, W. L., and H. F. Stephenson. 1959. Nature of the reactions of morocalcium phosphate monohydrate in soils: I. The solution that reads with the soil. Soil Sci. Soc. Amer. Proc. 23:12-18.

Logan, T. J. 1980. The role of soil and sediment chemistry in modeling nonpoint sources of phosphorus. In Environmental Impact of Nonpoint Source Pollution (Overcash, M.R. and Davidson, J.M., editors). Ann Arbor Science Publishers.

Logan, T.J., and E. D. McLean. 1973. Nature of phosphorus retention and adsorption with depth in soil columns. Soil Sci. Soc. Am. Proc. 37:351-355.

Lopez-Hernandez, D., and C. P. Burnham. 1973. Extraction methods for aluminum and iron in relation to phosphate adsorption. Commun. Soil Sci. Plant Anal. 4:9-16.

Lopez-Hernandez, I. D., and C. P. Burnham. 1974. The covariance of phosphate sorption with other soil properties in some British and tropical soils. J. Soil Sci. 25:196-206.

Lopez-Hernandez, I. D., and C. P. Burnham. 1974. The effect of pH on phosphate adsorption in soils. J. Soil Sci. 25:207-216.

Lopez-Hernandez, D., and C. P. Burnham. 1974. Phosphate adsorption by organic soils in Britain. Int. Congr. Soil Sci. Trans. 10th (Moscow, Russia) 11:73-80.

Low, P. F., and C. A. Black. 1947. Phosphate-induced decomposition of kaolinite. Soil Sci. Soc. Amer. Proc. 12:180-184.

Low, P. F., and C. A. Black. 1950. Reactions of phosphate with kaolinite. Soil Sci. 70:273-290.

Luff, B. B., and R. B. Reed. 1978. Enthalpy of solution of dipotassium orthophosphate at 25°C. J. Chem. Eng. Data 23:56-58.

Luff, B. B., and R. B. Reed. 1978. Low-temperature heat capacity and entropy of dipotassium orthophosphate. J. Chem. Eng. Data 23:58-60.

Luff, B. B., and R. B. Reed. 1978. Standard enthalpies of formation of monopotassium and dipotassium orthophosphate. J. Chem. Eng. Data 23:60-62.

Lung, W. S., R. P. Canale, and P. L. Freedman. 1976. Phosphorus models for eutrophic lakes. Water Res. 10:1101-1114.

Machenthum, K. M. 1965. "Nitrogen and Phosphorus in Water." U. S. Dept. of Health, Education and Welfare, Public Health Serv., Div. of Water Supply and Pollution Control, U. S. Govt. Printing Office, Washington, D. C.

McAuliffe, C. D., N. S. Hall, L. A. Dean, and S. B. Hendricks. 1948. Exchange reactions between phosphate and soil: hydroxylic surfaces of soil minerals. Soil Sci. Soc. Am. Proc. 12:119-123.

McCallister, D. L., and T. J. Logan. 1978. Phosphate adsorption-desorption characteristics of soils and bottom sediments in the Maumee river basin of Ohio. J. Environ. Qual. 7:87-92.

McDowell, H., T. M. Gregory, and W. E. Brown. 1977. Solubility of $Ca_5(PO_4)_3(OH)$ in the system $Ca(OH)_2$-H_3-PO_4-H_2O at 5, 15, 25, and 37°C. J. Res. Natl. Bur. Stand., Sect. A. pp. 273-281.

McLaughlin, J. R., J. C. Ryden, and J. K. Syers. 1977. Development and evaluation of a kinetic model to describe phosphate sorption by hydrous ferric oxide gel. Geoderma 18:295-307.

Mandal, L. N., and S. K. Khan. 1976. Influence of different moisture regimes on the transformation of applied phosphate in rice soils in its availability to rice plants. J. Indian Soc. Soil Sci. 24:374-381.

Manning, P. G. 1977. Moessbauer spectral studies of ferric phosphate interaction in sediments underlying oxic lake waters. Can. Mineral 15:422-426.

Mansell, R. S., H. M. Selim, P. Kanchanasut, J. M. Davidson, and J. G. A. Fiskell. 1977. Experimental and simulated transport of phosphorus through sandy soils. Water Resources Res. 13:189-194.

Marion, G. M., and K. L. Badcock. 1977. The solubilities of carbonates and phosphates in calcareous soils suspensions. Soil Sci. Soc. Am. J. 4:724-728.

Mattingly, G. E. G. 1975. Labile phosphate in soils. Soil Sci. 119: 369-375.

Mattson, S., E. Kouteler-Andersson, K. B. Miller, and K. Vahtrac. 1951. Phosphate relations of soil and plant. VIII. Electrokinetics, amphoteric behavior and Kgl. solubility relations. Lantbruks-Hogskol. Ann. 18:128-153.

May, J., J. R. Mettenry, and J. C. Ritchie. 1976. Phosphorus in the sediments of Lake Verret-Palourde, Louisiana. J. Miss. Acad. Sci. 21:413.

Moghimi, A., D. G. Lewis, and J. M. Oades. 1978. Release of phosphate from calcium phosphates by rhizosphere products. Soil Biol. Biochem. 10:227-281.

Moore, P. B., and A. R. Kampf. 1977. Schoonerite, a new zinc-manganese-iron phosphate mineral. Am. Mineral 62:246-249.

Mortimer, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. J. Ecol. 29:280-329.

Muljadi, D., A. M. Posner, and J. P. Quirk. 1966. The mechanism of phosphate adsorption by kaolinite, gibbsite, and pseudoboehmite. 1. The isotherms and the effect of pH on adsorption. J. Soil Sci. 17:212-228.

Munns, D. N., and R. L. Fox. 1976. The slow reactions which continue after phosphate adsorption: Kinetics and equilibrium in some tropical soils. Soil Sci. Soc. Am. J. 40:46-51.

Myszka, A., and M. Janowska. 1973. Phosphorus sorption of soils at low concentrations of the absorbate, determined by a chemical and radiometric method. Pol. J. Soil Sci. 6:27-35.

Nagarajah, S., A. M. Posner, and J. P. Quirk. 1970. Competitive adsorption of phosphate with polygalacturonate and other organic anions on kaolinite and oxide surfaces. Nature 228:83-85.

Neller, J. R. 1946. Mobility of phosphate in sandy soils. Soil Sci. Soc. Am. Proc. 11:227-230.

Novak, L. T., and D. C. Adriano. 1975. Phosphorus movement in soils: soil-orthophosphate reaction kinetics. J. Environ. Qual. 4:261-266.

Novak, L. T., D. C. Adriano, G. A. Coulman, and D. B. Shah. 1975. Phosphorus movement in soils: Theoretical aspects. J. Environ. Qual. 4:107-113.

Nriagu, J. O. 1976. Phosphate-clay mineral relations in soils and sediments. Can. J. Earth Sci. 13:717-736.

Obihara, C. H., and E. W. Russell. 1972. Specific adsorption of silicate and phosphate by soils. J. Soil Sci. 23:105-117.

Ohle, W. 1953. Phosphorus as the initial factor in the development of eutrophic waters. Vom Wasser. 20:11-23.

Olsen, S. R., and F. S. Watanabe. 1957. A method to determine a phosphorus adsorption maximum of soils as measured by the Langmuir isotherm. Soil Sci. Soc. Am. Proc. 21:144-149.

Olsen, S. R., R. A. Bowman, and F. S. Watanabe. 1977. Behavior of phosphorus in the soil and interactions with other nutrients. Phosphorus Agric. 31:31-46.

Olsen, S. R., R. A. Bowman, and F. S. Watanabe. 1977. Behavior of phosphorus in the soil and interactions with other nutrients. Phosphorus Agric. 70:7-16.

Owens, L. B., D. W. Nelson, and L. E. Sommers. 1977. Determination of inorganic phosphorus in oxalate extracts of soils. Soil Sci. Soc. Am. J. 41:148-149.

Overman, A. R., and R. L. Chu. 1977. A kinetic model of steady state phosphorus fixation in a batch reactor--1. Effect of soil solution ratio. Water Res. 11:771-775.

Overman, A. R., and R. L. Chu. 1977. A kinetic model of steady state phosphorus fixation in a batch reactor--11. Effect of pH. Water Res. 11:777-778.

Overman, A. R., and R. L. Chu. 1977. A kinetic model of steady state phosphorus fixation in batch reactor--111. Effect of solution reaction. Water Res. 11:779-781.

Ozanne, P. G., D. J. Kirton, and T. C. Shaw. 1961. The loss of phosphorus from sandy soils. Aust. J. Agric. Res. 12:409-423.

Parfitt, R. L., R. J. Atkinson, and R. St. C. Smart. 1975. The mechanism of phosphate fixation by iron oxides. Soil Sci. Soc. Am. Proc. 39:837-841.

Parfitt, R. L., A. R. Fraser, J. D. Russell, and V. C. Farmer. 1977. Adsorption on hydrous oxides. 11. Oxalate, benzoate, and phosphate on gibbsite. J. Soil Sci. 28:40-47.

Parfitt, R. L., A. D. Thomas, R. J. Atkinson, and R. St. C. Smart. 1974. Adsorption of phosphate of imogolite. Clays Clay Mineral 22:455-456.

Parks, G. A. 1965. The isoelectric points of solid oxides, solid hydroxides and aqueous hydroxo compex systems. Chem Res. 65:177-198.

Patrick, W. H., Jr., and R. A. Khalid. 1974. Phosphate release and sorption by soils and sediments: effect of aerobic and anerobic conditions. Science 186:53-55.

Perrott, K. W., A. G. Langdon, and A. T. Wilson. 1974. Sorption of phosphate by aluminum and iron(111)-hydroxy species on mica surfaces. Geoderma 12:223-231.

Piper, C. S. 1942. Soil and Plant Analysis. pp. 192-5. Univ. Adelaide. 365 pages.

Poranaond, K., and P. G. E. Searle. 1977. The effect of time of fertilizer-soil contact, distance of phosphate movement, and fertilizer solubility on phosphate availability to early growth of lowland rice. Plant Soil 46:391-404.

Pulford, I. D., and H. J. Duncan. 1975. The influence of pyrite oxidation products on the adsorption of phosphate by coal-mine waste. J. Soil Sci. 26:74-80.

Rajan, S. S. S. 1973. Phosphorus adsorption characteristics of Hawaiian soils and their relationships to equilibrium phosphorus concentrations required for maximum growth of millet. Plant Soil 39:519-532.

Rajan, S. S. S. 1975. Phosphate adsorption and the displacement of structural silicon in an allophane clay. J. Soil Sci. 26:250-256.

Rajan, S. S. S. 1976. Nature 262:45.

Rajan, S. S. S., and R. I. Fox. 1975. Phosphate adsorption by soils. 11. Reactions in tropical acid soils. Soil Sci. Soc. Am. Proc. 39:846-851.

Rajan, S. S. S., K. W. Perrott. 1975. Phosphate adsorption by synthetic amorphous aluminosilicates. J. Soil Sci. 26:257-266.

Rajan, S. S. S., K. W. Perrott, and W. M. H. Saunders. 1974. Identification of phosphate-reactive sites of hydrous alumina from proton consumption during phosphate adsorption at constant pH values. J. Soil Sci. 25:438-447.

Rajan, S. S. S., J. H. Watkinson. 1976. Adsorption of selenite and phosphate on an allophane clay. Soil Sci. Soc. Am. Proc. 40:51-54.

Raupach, M. 1963. Solubility of simple aluminum compounds expected in soils. III. Aluminum ions in soil solutions and aluminum phosphates in soils. Australian J. Soil Res. 1:46-54.

Ray, S. C., and S. C. Das. 1974. Adsorption and desorption of phosphate in clays and clay constituents in relation to pH and phosphate concentration in solution. 1. Clay minerals: hydrogen and aluminum clays. Indian Agric. 18:235-247.

Ray, S. C., and S. C. Das. 1976. Adsorption and desorption of phosphate in clays and clay constituents in relation to pH and phosphate concentration in solution. 11. Adsorption of phosphate in binary mixture of clay minerals. Indian Agric. 20:39-42.

Reddy, M. M. 1977. Crystallization of calcium carbonate in the presence of trace concentrations of phosphorus-containing anions. 1. Inhibition by phosphate and glycerophosphate ions at pH 8.8 and 25°C. J. Cryst. Growth 41:287-295.

Reddy, G. S., and Y. K. Reddy. 1977. Precipitation of manganese ammonium phosphate from homogeneous solution by urea hydrolysis. Indian J. Chem. 15A:352-353.

Rhodes, E. R. 1977. Simple phosphate sorption index on some soils of the humid tropics. Plant Soil 46:263-266.

Riemsdijk, W. H. van., F. A. Weststrate, and G. H. Bolt. 1975. Evidence for a new aluminum phosphate phase from reaction rate of phosphate with aluminum hydroxide. Nature 257:473-474.

Romkens, M. J. M., and D. W. Nelson, 1974. Phosphorus relationships in runoff from fertilized soils. J. Environ. Qual. 6:10-13.

Rothbaum, H. P., and A. G. Rohde. 1976. Long-term leaching of nutrients from magnesium ammonium phosphate at various temperatures. N.Z.J. Exp. Agric. 4:405-413.

Russell, E. W. 1973. The sources of plant nutrients in the soil: Phosphate. p. 555-579. In Soil condition and plant growth. Longman Press, N.Y.

Russell, E. W. 1973. The sources of plant nutrients in the soil: phosphate fertilizers. p. 580-603. In Soil condition and plant growth. Longman Press, N.Y.

Russell, J. D., R. L. Parfitt, P. R. Fraser, and V. C. Farmer. 1974. Surface structures of gibbsite, goethite, and phosphated geothite, Nature, Lond. 248:220-221.

Russell, R. D. 1963. Experiments on Cumulative Dressings of Fertilizers on Calcareous Soils in South-West England. 1.-Description of field experiments and soil analysis for phosphorus residues. J. Sci. Food Agric. 14:622-628.

Russell, R. S., J. B. Rickson, and S. N. Adams. 1954. Isotopic equilibria between phosphates in soil and their significance in the assessment of fertility by tracer methods. J. Soil Sci. 5:85-105.

Ryden, J. C., J. R. McLaughlin, and J. K. Syers. 1977a. Mechanisms of phosphate sorption by soils and hydrous ferric oxide gel. J. Soil Sci. 28:72-92.

Ryden, J. C., J. R. McLaughlin, and J. K. Syers. 1977b. Time-dependent sorpton of phosphate by soils and hydrous ferric oxides. J. Soil Sci. 28:585-595.

Ryden, J. C., and J. K. Syers. 1975. Rationalization of ionic strength and cation effects on phosphate sorption by soils. J. Soil Sci. 26:395-406.

Ryden, J. C., and J. K. Syers. 1976. Calcium retention in response to phosphate sorption by soils. Soil Sci. Soc. Am. J. 40:845-846.

Ryden, J. C., and J. K. Syers. 1977. Desorption and isotopic exchange relationships of phosphate sorbed by soils and hydrous ferric oxide gel. J. Soil Sci. 28:596-609.

Ryden, J. C., and J. K. Syers. 1977. Origin of the labile phosphate pool in soils. Soil Sci. 123:353-361.

Ryden, J. C., J. K. Syers, and R. F. Harris. 1973. Phosphorus in runoff and streams. Adv. Agron. 25:1-45.

Ryden, J. C., J. K. Syers, and J. R. McLaughlin. 1977. Effects of ionic strength on chemisorption and potential-determining sorption of phosphate by soils. J. Soil Sci. 28:62-71.

Sacheti, A. K., and S. N. Saxena. 1972. Availability of some soil phosphate reaction products. Indian Soc. Soil Sci. J. 20:219-224.

Sadler, J. M., and J. W. B. Stewart. 1977. Labile residual fertilizer phosphorus in Chernozemic soils. 1. Solubility and quantity-intensity studies. Can. J. Soil Sci. 57:65-73.

Sahrawat, K. L. 1977. EDTA extractable phosphorus in soils as related to available and inorganic phosphorus forms. Commun. Soil Sci. Plant Anal. 8:281-287.

Sanyal, S. K., and D. L. Deb. 1976. Effect of reaction time and reaction temperature on phosphorus and zinc availability in soil. J. Nucl. Agric. Biol. 5:54-60.

Sarangamath, P. A., B. N. Shinde, and S. Patnaik. 1977. ^{32}P tracer studies on the methods of increasing the efficiency of citrate soluble and insoluble phosphates for rice on acid soils. Soil Sci. 124:40-44.

Sarkar, D., M. C. Sarkar, and S. K. Ghosh. 1977. Reaction products from fertilizer phosphorus in alluvial soils of West Bengal. Fert. News, pp. 30-34.

Sarkar, D., M. C. Sarkar, and S. K. Ghosh. 1977. Soil-fertilizer phosphorus reaction products in lateritic soils of West Bengal. Fert. Technol. 14:43-48.

Sarkar, M. C. 1974. Effect of addition of fertilizers to soils of different textures on the equilibrium phosphate potential of soils. J. Indian Soc. Soil Sci. 22:84-85.

Saunders, W. M. H. 1965. Phosphate retention by New Zealand soils and its relationship to free sesquioxides, organic matter, and other soil properties. N.Z.J. Agric. Res. 8:30-57.

Sawhney, B. L. 1977. Predicting phosphate movement through soil columns. J. Environ. Qual. 6:86-89.

Sawhney, B. L., and D. E. Hill. 1975. Phosphate sorption characteristics of soils treated with domestic waste water. J. Environ. Qual. 4:342-346.

Shapiro, R. E., and M. Fried. 1959. Relative release and retentiveness of soil phosphates. Soil Sci. Soc. Am. Proc. 23:195-198.

Schwertmann, U. 1964. Differenzierung der Eisenoxide des Bodens durch Extraktion mit Ammoniumoxalat-Losung. Z. Pfl. Ernahr. Dung. Bodenk. 105:194-202.

Sharpley, A. N., R. W. Tillman, and J. K. Syers. 1977. Use of laboratory extraction data to predict losses of dissolved inorganic phosphate in surface runoff and tile drainage. J. Environ. Qual. 6:33-36.

Shipp, R. R., and Matelski. R. P. 1960. A microscopic determination of apatite and a study of phosphorus in some Nebraska soil profiles. Soil Sci. Soc. Amer. Proc. 24:450-452.

Shukla, S. S., J. K. Syers, J. D. H. Williams, D. E. Armstrong, and R. F. Harris. 1971. Sorption of inorganic phosphate by lake sediments. Soil Sci. Soc. Am. Proc. 35:244-249.

Sillen, L. G., and A. E. Martell. 1964. Chem. Soc. London, Spec. Publ. 17.

Sinclair, A. G. 1975. Reactions of fused calcium-magnesium phosphate and superphosphate on a highly phosphate-fixing soil. 1. Particle size effects. N.Z. J. Exp. Agric. 3:105-110.

Sinclair, A. G. 1975. Reaction of fused calcium-magnesium phosphate and superphosphate on a highly phosphate-fixing soil. 11. Placement effects. N.Z.J. Exp. Agric. 3:111-116.

Singh, B. B., and M. A. Tabatabai. 1977. Effects of soil properties on phosphate sorption. Commun. Soil Sci. Plant Anal. 8:97-107.

Singh, B. B., and M. A. Tabatabai. 1978. Effects of equilibrating salt solutions on phosphates sorption by soils. Commun. Soil Sci. Plant Anal. 7:677-688.

Singhania, R. A., P. K. Oomen, and N. N. Goswami. 1976. Transformation of applied phosphorus in neutral to alkaline alluvial and red soils. J. Nucl. Agric. Biol. 5:81-83.

Skopp, J., and A. W. Warrick. 1974. A two-phase model for miscible displacement of reactive solutes in soils. Soil Sci. Soc. Amer. Proc. 38:545-550.

Smith, E. A., P. T. S. Wong, and C. I. Mayfield. 1977. Effects of phosphorus from apatite on development of freshwater communities. J. Fish. Res. Board Can. 34:2405-2409.

Smith, J. M. 1970. Chemical Engineering Kinetics. McGraw-Hill, NY. Chap. 1.

Spencer, W. F. 1957. Distribution and availability of phosphates added to a Lakeland fine sand. Soil Sci. Soc. Am. Proc. 21:141-144.

Sree Ramulu, U. S., P. F. Pratt, and A. L. Page. 1967. Phosphorus fixation by soils in relation to extractable iron oxide and mineralogical composition. Soil Sci. Soc. Am. Proc. 31:193-196.

Steele, K. W. 1976. Effect of added phosphorus on the availability and forms of phosphorus present in two soils of the Manawatu-Rangitikei sand country. N.Z. J. of Agric. Res. 19:443-449.

Stewart, K. M., and G. A. Rohlich. 1967. Entrophication-A Review. Report to the State Water Control Board, California.

Stilwell, T. C., and T. G. Arscott. 1978. The relationship between fluoride-titratable (reactive) soil aluminum and plant growth. Soil Sci. 125:28-33.

Stoltenberg, N. L., and J. L. White. 1953. Selective loss of plant nutrients by erosion. Soil Science Soc. Amer. Proc. 17:406-410.

Stumm, W., and J. O. Leckie. 1971. Phosphate Exchange with Sediments. In *Proceedings 5th International Conference on Water Pollution*, Pergammon, New York.

Stumm, W., and J. J. Morgan. 1970. *Aquatic Chemistry*, Wiley-Interscience, New York.

Subbarao, Y. V., and R. Ellis, Jr. 1975. Reaction products of polyphosphates and orthophosphates with soils and influence on uptake of phosphorus by plants. Soil Sci. Soc. Am. Proc. 39:1085-1088.

Sudarsanan, K., R. A. Young, and A. J. Wilson. 1977. The structures of some Cadmium 'Apatites' $Cd_5(MO_4)_3$ X. 1. Determination of the structures of $Cd_5(VO_4)_31$, $Cd_5(PO_4)_3Br$, $Cd_5(A_5O_4)_3Br$, and $Cd_5(VO_4)_3Br$. Acta Crystallogr. B33:3136-3142.

Sutton, C. D., and D. Gunary. 1969. Phosphate equilibria in soil. p. 127-134. *In* Rorison, I.H. (ed.) Ecological aspects of the mineral nutrition of plants. Symp. of the British Ecological Soc., April 1968.

Syers, J. K., M. G. Browman, G. W. Smillie, and R. B. Corey. 1973. Phosphate sorption by soils evaluated by the Langmuir adsorption equation. Soil Sci. Soc. Am. Proc. 37:358-368.

Syers, J. K., T. D. Evans, J. D. H. Williams, and J. T. Murdock. 1971. Phosphate sorption parameters of representative soils from Rio Grande do Sul, Brazil. Soil Sci. 112:267-275.

Syers, J. K., R. Shah, and T. W. Walker. 1969. Fractionation of phosphorus in two allivial soils and particle-size separates. Soil Science 108:283-289.

Tahoun, S. A. 1976. The reaction of monocalcium phosphate with kaolinite. Egypt J. Soil Sci. 16:69-74.

Tahoun, S. A. 1976. The reaction of monocalcium phosphate with calcite. Egypt J. Soil Sci. 16:75-80.

Talibudeen, O. 1958. Isotopically exchangeable phosphorus in soils. 111. J. Soil Sci. 9:120-129.

Tamm, O. 1932. Über die oxalatmethode in der chemischen bodenanalyse. Stockholm Statens. Skogsforskingsinstitute Meddelanden. 27:1-20.

Taylor, A. W., and E. L. Gurney. 1962. Phosphate equilibrium in an acid soil. Soil Sci. 93:241-245.

Tomson, M. B., J. P. Barone, and G. H. Nancollas. 1977. Precise calcium phosphate determination. At. Absorpt. Newsl. 16:117-118.

Turner, F. T., and J. W. Gilliam. 1976. Effect of moisture and oxidation status of alkaline rice soils of India and Peru on the adsorption of soil phosphorus by an anion resin. Plant Soil 45:353-363.

Vakdyanathan, L. V., and P. H. Nye. 1970. The measurement and mechanism of ion diffusion in soils. VI. The effect of concentration and moisture content on the counter-diffusion of soil phosphate against chloride ion. J. Soil Sci. 21:15-27.

Vaidyanathan, L. V., and P. H. Nye. 1971. The measurement and mechanism of ion diffusion in soils. VII. Counter-diffusion of phosphate against chloride in a moisture-saturated soil. J. Soil Sci. 22: 94-100.

Vaidyanathan, L. V., and O. Talibudeen. 1968. Rate-controlling processes in the release of soil phosphate. J. Soil Sci. 19:

Vaidyanathan, L. V., and O. Talibudeen. 1970. Rate processes in the desorption of phosphate from soils by ion-exchange resins. J. Soil Sci. 2:173-183.

Vanderdeelen, J., N. Ines Pino, and L. Baert. 1973. Kinetics of phosphate adsorption in a soil derived from volcanic ash. Turrialba 23:291-296.

Van Riemsdijk, W. H., F. A. Weststrate, and G. H. Bolt. 1975. Evidence for a new aluminum phosphate phase from reaction rate of phosphate with aluminum hydroxide. Nature 257:473-474.

Van Riemsdijk, W. H., F. A. Weststrate, and J. Beek. 1977. Phosphates in soils treated with sewage water: 111. Kinetic studies on the reaction of phosphate with aluminum compounds. J. Environ. Qual. 6:26-29.

Vijayachandran, P. K., and R. D. Harter. 1975. Evaluation of phosphorus adsorption by a cross section of soil types. Soil Sci. 119:119-126.

Vollenweider, R. A. 1968. "Scientific Fundamentals of the Entrophication of Lakes and Flowing Waters with Particular Reference to Nitrogen and Phosphorus as Factors in Entrophication." OECD, Paris.

Wang, W. C. 1974. Adsorption of phosphate by river particulate matter. Water Resour. Bull. 10:662-671.

Webber, M. D., and G. J. Racz. 1970. Soluble complexes in the systems dicalcium phosphate dihydrate or dimagnesium phosphate trihydrate equilibrated with aqueous salt solutions. Can. J. Soil Sci. 50: 242-253.

Weir, C. C. 1977. Phosphate fixation in Jamaican latosolic soils. Trop. Agric. (Trinidad) 54:87-93.

Weir, C. C., and R. J. Soper. 1962. Adsorption and exchange studies of phosphorus in some Manitoba soils. Can. J. Soil Sci. 42:31-42.

White, R. E., and P. H. T. Beckett. 1964. Studies on the phosphate potentials of soils 1. Plant Soil 20:1-16.

White, R. E., and A. W. Taylor. 1977. Effect of pH on phosphate adsorption and isotopic exchange in acid soils at low and high additions of soluble phosphate. J. Soil Sci. 28:48-61.

White, R. E., and A. W. Taylor. 1977. Reactions of soluble phosphate with acid soils: the interpretation of adsorption-desorption isotherms. J. Soil. Sci. 28:314-328.

Wiklander, L. 1950. Kinetics of phosphate exchange in soils. Ann. R. Agr. Coll. Sweden 17:407-424.

Wild, A. 1950. Effects of salts on the retention of phosphate by clay at various pH values. Trans. 4th Int. Congr. Soil Sci., Amsterdam. 1:1946-1948.

Wildung, R. E., R. L. Schmidt, and R. C. Routson. 1977. The phosphorus status of eutrophic lake sediments as related to changes in limnological conditions--phosphorus mineral components. J. Environ. Qual. 6:100-104.

Williams, E. G., N. M. Scott, and M. J. McDonald. 1958. Soil properties and phosphate sorption. J. Sci. Food Agric. 9:551-559.

Wondrausch, J. 1969. Phosphorus sorption in mucky-peat soils. Pol. J. Soil Sci. 2:97-106.

Yuan, T. L., and H. L. Breland. 1969. Correlation of Al and Fe as extracted by different reagents with phosphate retention in several soil groups. Soil Crop Sci. Soc. Fla. Proc. 29:78-86.

TYPING GUIDE SHEET

APPENDIX A

Tables of Adsorption Isotherm Parameters

EPA-287 (Cin.)
(4-76)

Table A1. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Ametryne and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
ALTURA L	6	8.0	2.13	27.6	2.5500E+00	.	.	1.1972E+02
COTO C	6	7.7	1.84	14.0	2.5100E+00	.	.	1.3641E+02
GUANICA C	6	8.1	2.77	52.1	4.0400E+00	.	.	1.4585E+02
RIO PEDRAS SC	6	4.9	2.02	11.5	3.2000E+00	.	.	1.5842E+02
CATANO S	6	7.9	1.21	6.9	2.0800E+00	.	.	1.7190E+02
MERCEDITA SC	6	8.1	1.38	19.9	2.3800E+00	.	.	1.7246E+02
FE CL	6	7.5	1.96	27.6	3.7200E+00	.	.	1.8980E+02
MABI CL	6	5.7	2.82	31.0	5.5800E+00	.	.	1.9787E+02
AGUADILLA LS	6	7.4	1.44	10.0	3.0800E+00	.	.	2.1389E+02
VEGA ALTA SL	6	5.0	2.02	5.6	5.1400E+00	.	.	2.5446E+02
CATALINA C	6	4.7	1.09	11.8	2.7800E+00	.	.	2.5505E+02
FRATERNIDAD C	6	6.3	1.21	36.0	3.3400E+00	.	.	2.7603E+02
SAN ANTON L	6	6.7	1.55	26.1	4.3300E+00	.	.	2.7935E+02
NIPE C	6	5.7	3.06	11.9	9.5200E+00	.	.	3.1111E+02
PANDURA SL	6	5.7	1.15	7.7	3.6300E+00	.	.	3.1565E+02
BAYAMON SCL	6	4.7	0.98	5.0	3.2000E+00	.	.	3.2653E+02
FRATERNIDAD C	6	5.9	2.42	58.0	8.1400E+00	.	.	3.3636E+02
CAYAGUA SL	6	5.2	1.15	7.3	3.9700E+00	.	.	3.4522E+02
AGUIRRE CL	6	9.0	0.75	14.3	2.7600E+00	.	.	3.6800E+02
JOSEFA SL	6	6.0	1.90	16.8	7.1600E+00	.	.	3.7684E+02
ALONSO C	6	5.1	1.84	13.8	7.1100E+00	.	.	3.8641E+02
COLOSO CL	6	5.7	2.13	23.0	9.1600E+00	.	.	4.3005E+02
CIALITOS C	6	5.4	2.82	18.6	1.3320E+01	.	.	4.7234E+02
HUMATA SCL	6	4.5	0.98	10.1	4.7000E+00	.	.	4.7959E+02
MUCARA L	6	5.8	1.90	19.6	1.0460E+00	.	.	5.5053E+02
TAA SL	6	6.0	0.34	8.0	2.0800E+00	.	.	6.1176E+02
MOCA C	6	5.8	2.19	31.0	1.3610E+01	.	.	6.2146E+02

Continued

Table A1. (Continued)

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
VIA L	6	5.1	1.32	39.9	8.4900E+00	.	.	6.4318E+02
JUNCOS SC	6	6.2	1.55	13.4	1.0900E+01	.	.	7.0323E+02
TALANTE SL	6	5.1	0.80	4.0	6.1900E+00	.	.	7.7375E+02
TOA L	6	5.3	1.15	13.0	9.7200E+00	.	.	8.4522E+02
FORTUNA SCL	6	5.4	1.90	23.3	1.8230E+01	.	.	9.5947E+02

*See Table A39 for corresponding literature citation. Same comment applies to Tables A2-A38.

Table A2. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Amiben and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
POYGAN SICL	36	7.2	5.70	.	2.4000E-01	.	.	4.2105E+00
KEWAUNEE C	36	6.4	2.19	.	1.1000E-01	.	.	5.0228E+00
FARGO C	9	7.9	4.56	30.1	3.0000E-01	.	.	6.5789E+00
ANSELMO SL	9	7.0	0.98	7.0	1.0000E-01	.	.	1.0204E+01
KEITH SL	9	6.2	1.67	11.6	3.0000E-01	.	.	1.7964E+01
MONONA SL	9	5.8	2.42	17.5	5.0000E-01	.	.	2.0661E+01
ELLA LS	36	3.8	0.92	.	2.4000E-01	.	.	2.6087E+01
SHARPSBURG SCL	9	5.8	2.54	24.5	1.0000E+00	.	.	3.9370E+01
GALLION FSL	34	6.2	0.35	2.8	1.1000E+00	.	.	3.1429E+02
TALOKA SL	34	6.4	0.40	4.6	1.9000E+00	.	.	4.7500E+02
CROWLEY SL	34	6.5	0.92	12.6	4.5000E+00	.	.	4.8913E+02
SHARKEY C	34	6.7	0.75	33.4	6.5000E+00	.	.	8.6667E+02

Table A3. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Atrazine and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
KULA RP	38	5.9	12.70	.	6.0000E+00	.	.	4.7244E+01
KAPAA HFL	38	4.4	5.70	.	2.9000E+00	.	.	5.0877E+01
SANDY L	29	7.1	1.93	11.0	1.0000E+00	.	.	5.1813E+01
LAKELAND SL	13	6.2	1.90	2.9	1.0000E+00	1.0000	0.85	5.2632E+01
KAIPOIOI LBF	38	5.4	16.70	.	9.3000E+00	.	.	5.5689E+01
BOYCE L	16	8.0	1.27	20.0	7.7800E-01	.	.	6.1260E+01
PONDER SIL	16	7.7	1.67	31.9	1.2000E+00	.	.	7.1856E+01
METOLIUS SL	16	7.1	0.80	18.5	6.1500E-01	.	.	7.6875E+01
CHEHALIS SL	16	5.2	0.98	16.9	8.2700E-01	.	.	8.4388E+01
KEITH FSL	19	6.3	1.67	.	1.4930E+00	1.4930	0.83	8.9401E+01
BEGBROKE S L	7	7.1	1.11	.	1.0000E+00	.	.	9.0090E+01
QUINCY SL	16	8.0	0.28	11.0	2.6000E-01	.	.	9.2857E+01
VALENTINE LFS	19	5.9	0.80	.	7.6800E-01	0.7680	0.81	9.6000E+01
CEIL	42	5.6	0.90	6.8	8.9000E-01	0.8900	1.04	9.8889E+01
BATES SL	11	6.5	0.80	9.3	8.0000E-01	.	.	1.0000E+02
MOLOKAI LHL	38	6.3	2.30	.	2.3000E+00	.	.	1.0000E+02
DARK SL	29	6.3	12.00	18.0	1.2300E+01	.	.	1.0250E+02
GILA SIC	16	8.0	0.63	29.1	6.4900E-01	.	.	1.0302E+02
WOODBURN SIL	16	5.2	1.32	12.8	1.4480E+00	.	.	1.09705+02
EUSTIS	42	5.6	0.56	5.2	6.2000E-01	0.6200	0.79	1.1071E+02
MONONA SICL	19	5.8	1.67	.	1.9240E+00	1.9240	0.85	1.1521E+02
MENFRO SL	11	5.3	1.38	9.1	1.7000E+00	.	.	1.2319E+02
DESCHUTES SL	16	5.9	0.51	12.9	6.7600E-01	.	.	1.3255E+02
ELDON SL	11	5.9	1.73	12.9	2.5000E+00	.	.	1.4434E+02
HAGERSTOWN SICL	13	5.5	2.48	12.5	3.7000E+00	3.7000	0.87	1.4919E+02
SHELBY L	11	4.3	2.07	20.1	3.2000E+00	.	.	1.5459E+02
WEBSTER	42	7.3	3.87	54.7	6.0300E+00	6.0300	0.73	1.5581E+02
CHILLUM SIL	13	4.6	2.54	7.6	4.0000E+00	4.0000	0.87	1.5748E+02

(Continued)

Table A3. (Continued)

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
OSWEGO SCL	11	6.4	1.67	21.0	2.7000E+00	.	.	1.6168E+02
WEHADKEE SIL	13	5.6	1.09	10.2	1.8000E+00	1.8000	0.84	1.6514E+02
DRUMMER C L	25	8.0	3.63	40.0	6.3000E+00	.	.	1.7355E+02
PUTNAM SL	11	5.3	1.09	12.3	1.9000E+00	.	.	1.7431E+02
LINTONIA LS	11	5.3	0.34	3.2	6.0000E-01	.	.	1.7647E+02
SHARPSBURG SICL	19	5.2	2.19	.	3.8900E+00	3.8900	0.83	1.7763E+02
DRUMMER C L	25	6.0	3.63	40.0	6.5000E+00	.	.	1.7906E+02
MARSHALL SCL	11	5.4	2.42	21.3	4.5000E+00	4.5000	1.00	1.8595E+02
BAXTER CSL	22	6.0	1.21	11.2	2.3000E+00	.	.	1.9008E+02
SALIX L	11	6.3	1.21	17.9	2.3000E+00	.	.	1.9008E+02
NEWTONIA SL	11	5.2	0.92	8.8	1.8000E+00	.	.	1.9565E+02
SUMMIT SC	11	4.8	2.82	35.1	5.6000E+00	.	.	1.9858E+02
CUMBERLAND SL	11	6.4	0.69	6.5	1.4000E+00	.	.	2.0290E+02
GERALD SL	11	4.7	1.55	11.0	3.2000E+00	.	.	2.0645E+02
LEBANON SL	11	4.9	1.04	7.7	2.2000E+00	.	.	2.1154E+02
CLARKSVILLE CSL	11	5.7	0.80	5.7	1.7000E+00	.	.	2.1250E+02
SHARKEY C	11	5.0	1.44	28.2	3.1000E+00	.	.	2.1528E+02
KNOX SL	11	5.4	1.67	18.8	3.6000E+00	.	.	2.1557E+02
DRUMMER C L	25	5.3	3.63	40.0	8.2000E+00	.	.	2.2590E+02
GRUNDY SCL	11	5.6	2.07	13.5	4.8000E+00	.	.	2.3188E+02
WAVERLY SL	11	6.4	1.15	12.8	3.0000E+00	.	.	2.6087E+02
MARIAN SL	11	4.6	0.80	9.9	2.2000E+00	.	.	2.7500E+02
WABASH C	11	5.7	1.27	40.3	3.7000E+00	.	.	2.9134E+02
SARPY L	11	7.1	0.75	14.3	2.2000E+00	.	.	2.9333E+02
DRUMMER C L	25	4.7	3.63	40.0	1.0700E+01	.	.	2.9477E+02
LINDLEY L	11	4.7	0.86	6.9	2.6000E+00	.	.	3.0233E+02
DRUMMER C L	25	3.9	3.63	40.0	1.2600E+01	.	.	3.4711E+02
UNION SL	11	5.4	1.04	6.8	4.1000E+00	.	.	3.9423E+02

Table A4. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Carbofuran and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
SEDIMENT B	45	7.1	1.85	.	3.0000E-01	0.3000	0.90	1.6216E+01
SEDIMENT A	45	7.7	1.50	.	3.3000E-01	0.3300	1.03	2.2000E+01
VERSAILLES	45	6.4	1.10	.	2.6000E-01	0.2600	0.88	2.3701E+01
HUMUS	45	6.8	10.97	.	3.4800E+00	3.4800	0.91	3.1723E+01
LIMAGNE	45	8.0	2.08	.	7.2000E-01	0.7200	1.03	3.4615E+01
CHALCUS	45	8.1	1.62	.	6.1000E-01	0.6100	0.97	3.7654E+01
EARTH/HUMUS	45	6.5	4.16	.	1.6500E+00	1.6500	0.99	3.9663E+01

Table A5. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Chlorobromuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
WEYBURN OXBOW L	18	6.5	3.72	.	2.0300E+01	20.3000	0.83	5.4570E+02
REGINA HEAVY C	18	7.7	2.39	.	1.7800E+01	17.8000	0.71	7.4477E+02
ASQUITH SL	18	7.5	1.02	.	7.9000E+00	7.9000	0.73	7.7451E+02
INDIAN HEAD CL	18	7.8	2.34	.	2.2800E+01	22.8000	0.68	9.7436E+02
MELFORT L	18	5.9	6.05	.	1.1730E+02	117.3000	0.45	1.9388E+03

Table A6. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Chloroxuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
TOLL FARM HP	8	7.4	11.70	41.0	3.3000E+02	.	.	2.8205E+03
GREAT HOUSE SL	8	6.3	12.00	18.0	4.7500E+02	.	.	3.9583E+03
ROSEMAUNDE SCL	8	6.7	1.76	14.0	7.0000E+01	.	.	3.9773E+03
TRANSCOED SICL	8	6.2	3.69	.	1.7500E+02	.	.	4.7425E+03
WEED RES. SL	8	7.1	1.93	11.0	1.2000E+02	.	.	6.2176E+03

Table A7. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Chlorthiamid and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
SOIL 1	33	.	19.20	.	9.8000E+00	.	.	5.1042E+01
SOIL 5	33	.	3.93	.	3.6000E+00	.	.	9.1603E+01
SOIL 3	33	.	4.67	.	4.8000E+00	.	.	1.0278E+02
SOIL 4	33	.	4.56	.	4.7000E+00	.	.	1.0307E+02
SOIL 2	33	.	5.56	.	6.0000E+00	.	.	1.0791E+02
SOIL 6	33	.	3.37	.	4.5000E+00	.	.	1.3353E+02

Table A8. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Cis-Telone and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
HUMUS S	22	.	3.17	.	1.4000E+01	.	.	4.4164E+02
PEATY S	22	.	10.39	.	4.7000E+01	.	.	4.5236E+02
HUMUS S	22	.	3.17	.	2.2000E+01	.	.	6.9401E+02
PEATY S	22	.	10.39	.	7.8000E+01	.	.	7.5072E+02
HUMUS S	22	.	3.17	.	3.8000E+01	.	.	1.1987E+03
PEATY S	22	.	10.39	.	1.3000E+02	.	.	1.2512E+03

Table A9. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Dicamba and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
INDIAN HEAD L	41	7.8	2.35	.	3.0000E-02	.	.	1.2766E+00
MELFORT L	17	5.9	6.05	.	8.0000E-02	0.0800	1.30	1.3223E+00
WEYBURN OXBOW L	41	6.5	3.72	.	5.0000E-02	.	.	1.3441E+00
WEYBURN OXBOW L	17	6.5	3.72	.	7.0000E-02	0.0700	1.07	1.8817E+00
MELFORT L	41	5.9	6.05	.	3.0000E-01	.	.	4.9587E+00

Table A10. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Dimethylamine and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
WEYBURN OXBOW L	17	6.5	3.73	.	1.1700E+01	11.7000	1.00	3.1367E+02
INDIAN HEAD L	17	7.8	2.35	.	9.2000E+00	9.2000	0.99	3.9149E+02
ASQUITH SL	17	7.5	1.02	.	4.5000E+00	4.5000	0.99	4.4118E+02
REGINA HEAVY C	17	7.7	2.40	.	1.2000E+01	12.0000	1.00	5.0000E+02
MELFORT L	17	5.9	6.17	.	3.2600E+01	32.6000	1.00	5.2836E+02

Table A11. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Dipropetryn and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
COBB S	30	7.3	0.34	3.8	1.3200E+00	1.3200	0.86	3.8824E+02
TELLER FSL	30	5.7	0.75	8.6	6.1800E+00	6.1800	0.86	8.2400E+02
PORT SIC	30	6.3	1.04	17.9	8.9100E+00	8.9100	0.81	8.5673E+02
BREWER CL	30	5.8	1.61	13.5	1.8500E+01	18.5000	0.89	1.1491E+03
COBB	30	5.3	1.21	9.0	3.2500E+01	32.5000	0.73	2.6860E+03

Table A12. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Disulfoton and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
ELKH RN SL	15	6.0	0.86	.	5.0100E+00	5.0100	0.94	5.8256E+02
PEACOCK	15	7.6	11.00	74.0	7.0300E+01	70.3000	0.94	6.3909E+02
BROADBALK	1	8.1	0.90	10.4	5.8000E+00	5.8000	1.01	6.4444E+02
ISLEHAM	1	7.5	7.60	44.8	4.9100E+01	49.1000	0.87	6.4605E+02
BOTTISHAM	1	7.7	8.80	48.2	5.8600E+01	58.6000	0.97	6.6591E+02
PRICKWILLOW	1	5.1	15.00	83.4	1.0050E+02	100.5000	1.00	6.7000E+02
WORLINGTON	1	8.1	0.70	6.3	5.3000E+00	5.3000	1.09	7.5714E+02
BROADBALK	1	7.8	2.70	19.8	2.1500E+01	21.5000	1.00	7.9630E+02
SPINNEY	1	7.2	12.00	66.4	9.5700E+01	95.7000	0.80	7.9750E+02
OAKINGTON	1	7.2	1.80	14.0	1.6000E+01	16.0000	0.92	8.8889E+02
STRETHAM	1	7.5	1.40	13.0	1.4700E+01	14.7000	0.81	1.0500E+03
WOBURN	1	6.5	1.80	10.7	2.0000E+01	20.0000	1.00	1.1111E+03
WICKEN	1	8.0	1.70	21.9	2.0300E+01	20.3000	0.80	1.1941E+03
MOULTON	1	8.1	1.70	10.6	2.1100E+01	21.1000	0.81	1.2412E+03
WOBURN	1	6.8	1.10	10.2	1.4900E+01	14.9000	0.93	1.3545E+03
WOBURN	1	6.8	1.30	10.6	2.0500E+01	20.5000	0.85	1.5769E+03
SWEENEY SCL	15	6.3	0.65	.	1.1490E+01	11.4900	0.98	1.7677E+03
ISLEHAM	1	6.3	2.80	18.2	5.5500E+01	55.5000	0.88	1.9821E+03
HUGO GRAVELLY SL	15	5.5	0.12	.	3.0300E+00	3.0300	0.98	2.5250E+03
TIERRA CL	15	6.2	0.33	.	3.6860E+01	36.8600	1.05	1.1170E+04

Table A13. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Diuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
IREDELL C	12	5.6	6.17	20.9	9.5200E-01	.	.	1.5429E+01
ONTARIO C	12	5.9	0.86	8.4	2.0800E-01	.	.	2.4186E+01
LAKELAND SL	12	6.2	1.88	2.9	1.0980E+00	.	.	5.8404E+01
TIFTON LS	12	4.9	0.56	2.4	6.1800E-01	.	.	1.1036E+02
BENEVOLA C	12	7.6	1.30	20.1	1.4930E+00	.	.	1.1485E+02
BELTSVILLE SIL	12	4.3	1.40	4.2	1.6670E+00	.	.	1.1933E+02
BERKLEY C	12	7.3	0.99	34.4	1.2500E+00	.	.	1.2626E+02
BERKLEY SIC	12	7.1	4.63	33.7	5.8700E+00	.	.	1.2678E+02
WEHADKEE SIL	12	5.6	1.11	10.2	1.4100E+00	.	.	1.2703E+02
BENEVOLA SIC	12	7.7	2.70	19.5	3.6210E+00	.	.	1.3411E+02
TRIPP L	12	7.6	0.86	14.7	1.1730E+00	.	.	1.3640E+02
RUSTON SL	12	5.1	1.05	3.4	1.4930E+00	.	.	1.4219E+02
CECIL SC	12	5.3	1.09	3.6	1.5790E+00	.	.	1.4486E+02
STERLING CL	12	7.7	0.94	22.5	1.4100E+00	.	.	1.5000E+02
CHRISTIANA L	12	4.4	0.57	5.6	8.8200E-01	.	.	1.5474E+02
ASCALON SCL	12	7.3	0.85	12.7	1.3290E+00	.	.	1.5635E+02
OOSTER SIL	12	4.7	1.31	6.8	2.1430E+00	.	.	1.6359E+02
HAGERSTOWN SICL	12	7.5	1.30	8.8	2.1430E+00	.	.	1.6485E+02
CHESTER L	12	4.9	1.67	5.2	2.8130E+00	.	.	1.6844E+02
GARLAND C	12	7.7	0.65	23.2	1.0980E+00	.	.	1.6892E+02
CATALINA C	6	4.7	1.09	11.8	1.8600E+00	.	.	1.7064E+02
THURLOW CL	12	7.7	1.25	21.6	2.1430E+00	.	.	1.7144E+02
HAGERSTOWN SICL	12	5.5	2.48	12.5	4.2590E+00	.	.	1.7173E+02
RIO PIEDRAS SI C	6	4.9	2.02	11.5	3.6300E+00	.	.	1.7970E+02
CHILLUM CIL	12	4.6	2.54	7.6	4.6150E+00	.	.	1.8169E+02
TOLEDO SIC	12	5.5	2.80	29.8	5.6380E+00	.	.	2.0136E+02

(Continued)

Table A13. (Continued)

Soil	Article* No.	Soil Properties pH	 O.C. (%)	 C.E.C. (me/100g)	Adsorption Parameters K_D	 K	 N	 K_{oc}
MUCARA L	6	5.8	3.06	19.6	6.5300E+00	.	.	2.1340E+02
BARNES CL	12	7.4	3.98	33.8	8.5140E+00	.	.	2.1392E+02
HUMALTA SI C L	6	4.5	0.98	10.1	2.1300E+00	.	.	2.1735E+02
BOSKET SIL	12	5.8	0.57	8.4	1.2500E+00	.	.	2.1930E+02
TRUCKTON SL	12	7.0	0.25	4.4	5.5600E-01	.	.	2.2240E+02
CROSBY SIL	12	4.8	1.90	11.5	4.2590E+00	.	.	2.2416E+02
IRDELL SIL	12	5.4	3.04	17.0	6.9050E+00	.	.	2.2714E+02
BAYMON S C L	6	4.7	0.98	5.0	2.2900E+00	.	.	2.3367E+02
DUNDEE SICL	12	5.0	0.96	18.1	2.2460E+00	.	.	2.3396E+02
PANTURA S L	6	5.7	2.02	7.7	4.7300E+00	.	.	2.3416E+02
BEGBROKE S L	7	7.1	1.11	.	2.7000E+00	.	.	2.4324E+02
MERCEDITA SI C	6	8.1	2.19	19.9	5.4600E+00	.	.	2.4932E+02
ALONSO C	6	5.1	1.84	13.8	4.6300E+00	.	.	2.5163E+02
AQUIRRE CL	6	9.0	1.84	13.8	4.6300E+00	.	.	2.5163E+02
ALTURA L	6	8.0	2.13	27.6	5.3600E+00	.	.	2.5164E+02
CAYAGUA S L	6	5.2	1.15	7.3	2.9600E+00	.	.	2.5739E+02
SHARKEY C	12	6.2	2.25	40.2	6.3640E+00	.	.	2.8284E+02
TALANTE S L	6	5.1	0.80	4.0	2.3600E+00	.	.	2.9500E+02
FE C L	6	7.5	1.96	27.6	5.8600E+00	.	.	2.9898E+02
TOA L	6	5.3	1.15	13.0	3.5600E+00	.	.	3.0957E+02
VEGA ALTA S L	6	5.0	2.02	5.6	6.3000E+00	.	.	3.1188E+02
CATANO S	6	7.9	1.21	6.9	3.9000E+00	.	.	3.2231E+02

(Continued)

Table A13. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
AQUADILLA LS	6	7.4	1.44	10.0	4.7300E+00	.	.	3.2847E+02
KEYPORT SIL	10	5.4	1.21	.	4.0000E+00	4.0000	1.25	3.3058E+02
GUANICA C	6	8.1	2.77	52.1	9.3900E+00	.	.	3.3899E+02
TOA S L	6	6.0	0.34	8.0	1.2600E+00	.	.	3.7059E+02
BRIDGETS SIL	8	8.0	3.09	24.0	1.2000E+01	.	.	3.8835E+02
VIA L	6	5.1	1.32	39.9	5.1300E+00	.	.	3.8864E+02
TRAWSCOED SICL	8	6.2	3.69	12.0	1.6000E+01	.	.	4.3360E+02
CIALITOS C	6	5.4	2.82	18.6	1.2400E+01	.	.	4.3972E+02
TOLL FARM HP	8	7.4	11.70	41.0	5.3000E+01	.	.	4.5299E+02
COTO C	6	7.7	1.84	14.0	9.3600E+00	.	.	5.0870E+02
MABI C	6	7.0	2.82	55.2	1.4460E+01	.	.	5.1277E+02
FRATERNIDAD C	6	5.9	2.92	58.0	1.5890E+01	.	.	5.4418E+02
REGINA HEAVY C	18	7.7	2.39	.	1.3400E+01	13.4000	0.70	5.6067E+02
INDIAN HEAD CL	18	7.8	2.34	.	1.3300E+01	13.3000	0.78	5.6838E+02
COLOSO C L	6	5.7	2.13	23.0	1.2160E+01	.	.	5.7089E+02
FRATERNIDAD C	6	6.3	1.21	36.0	6.9600E+00	.	.	5.7521E+02
ROSEMAUNDE SCL	8	6.7	1.76	14.0	1.0200E+01	.	.	5.7955E+02
CECIL LS	10	5.8	0.40	.	2.4000E+00	2.4000	0.95	6.0000E+02
GREAT HOUSE S L	8	6.3	12.00	18.0	7.5000E+01	.	.	6.2500E+02
MOCA C	6	5.8	1.90	31.0	1.2030E+01	.	.	6.3316E+02
JOSEFA SIL	6	6.0	1.90	16.8	1.2060E+01	.	.	6.3474E+02
JUNCOS SI C	6	6.2	1.55	13.4	1.0100E+01	.	.	6.5161E+-2
KIRTON SI	8	7.6	1.50	13.0	1.0000E+01	.	.	6.6667E+02
ASQUITH SL	18	7.5	1.02	.	6.9000E+00	6.9000	0.63	6.7647E+02
WEED RES. SL	8	7.1	1.93	11.0	1.3600E+01	.	.	7.0466E+02

(Continued)

Table A13. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
FORTUNA SI C L	6	5.4	1.90	23.3	1.3400E+01	.	.	7.0526E+02
BOXWORTH C	8	7.9	2.08	22.0	1.5000E+01	.	.	7.2115E+02
WEYBURN OXBOW L	18	6.5	3.72	.	2.6900E+01	26.9000	0.55	7.2312E+02
LISCOMBE SL	8	6.2	3.45	13.0	2.5000E+01	.	.	7.2464E+02
MABI CL	6	5.7	1.38	31.0	1.0330E+01	.	.	7.4855E+02
VALENTINE LFS	40	6.6	0.80	10.1	6.5000E+00	.	.	8.1250E+02
MONONA SICL	40	6.5	1.67	21.2	1.4300E+01	.	.	8.5629E+02
TERRINGTON SI	8	8.0	1.54	15.0	1.4000E+01	.	.	9.0909E+02
SAN ANTON L	6	6.7	1.55	26.1	1.5800E+01	.	.	1.0194E+03
NIPE CL	6	5.7	1.15	11.9	1.5100E+01	.	.	1.3130E+03
MELFORT L	18	5.9	6.05	.	8.3300E+01	83.3000	0.95	1.3769E+03

Table A14. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Fenuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
ROSEMAUNDE SCL	8	6.7	1.76	14.0	3.4000E-01	.	.	1.9318E+01
TRAWSCOED SICL	8	6.2	3.69	12.0	7.3000E-01	.	.	1.9783E+01
WEED RES. SL	8	7.1	1.93	11.0	4.4000E-01	.	.	2.2798E+01
TOLL FARM HP	8	7.4	11.70	41.0	2.9000E+00	.	.	2.4786E+01
ASQUITH SL	18	7.5	1.02	.	3.0000E-01	0.3000	0.97	2.9412E+01
WEYBURN OXBOW L	18	6.5	3.72	.	1.1000E+00	1.1000	0.92	2.9570E+01
REGINA HEAVY C	18	7.7	2.39	.	8.0000E-01	0.8000	0.93	3.3473E+01
GREAT HOUSE S L	8	6.3	12.00	18.0	4.7000E+00	.	.	3.9167E+01
INDIAN HEAD CL	18	7.8	2.34	.	1.6000E+00	1.6000	0.85	6.8376E+01
MELFORT L	18	5.9	6.05	.	8.2000E+00	8.2000	0.68	1.3554E+02

Table A15. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Lindane and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
FOX SL	39	.	1.84	.	1.7300E+01	.	.	9.4022E+02
BROOKSTON	39	.	2.10	.	2.2700E+01	.	.	1.0810E+03
HONEYWOOD LS	39	.	1.67	.	2.0400E+01	.	.	1.2216E+03

Table A16. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Linuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	 O.C. (%)	 C.E.C. (me/100g)	Adsorption Parameters K_D	 K	 N	 K_{oc}
COLTS NECK	20	4.2	1.20	7.7	1.4940E+00	.	.	1.2450E+02
DARK SL	29	6.3	12.00	18.0	1.7000E+01	.	.	1.4167E+02
DUTCHESS	20	5.5	2.90	12.7	1.1748E+01	.	.	4.0510E+02
WHIPPANY	20	5.6	1.90	9.4	8.3080E+00	.	.	4.3726E+02
WHIPPANY	20	5.6	1.90	9.4	8.9030E+00	.	.	4.6858E+02
WEYBURN OXBOW L	18	6.5	3.72	.	1.9100E+01	19.1000	0.70	5.1344E+02
SASSAFRAS	20	5.2	2.00	7.7	1.0286E+01	.	.	5.1430E+02
DUTCHESS	20	5.3	2.90	12.7	1.5417E+01	.	.	5.3162E+02
TOLL FARM HP	8	7.4	11.70	41.0	6.3000E+01	.	.	5.3846E+02
COLLINGTON	20	5.0	2.60	12.8	1.4180E+01	.	.	5.4538E+02
WASHINGTON	20	6.0	2.40	11.2	1.3391E+01	.	.	5.5796E+02
WASHINGTON	20	6.2	2.40	11.2	1.3391E+01	.	.	5.5796E+02
SQUIRES	20	6.5	1.70	7.0	9.7930E+00	.	.	5.7606E+02
COOLINGTON	20	4.7	2.60	12.8	1.5048E+01	.	.	5.7877E+02
SANDY L	29	7.1	1.93	11.0	1.1400E+01	.	.	5.9067E+02
SASSAFRAS	20	5.2	2.00	7.7	1.2000E+01	.	.	6.0000E+02
GREAT HOUSE SL	8	6.3	12.00	18.0	7.3000E+01	.	.	6.0833E+02
ANNANDALE	20	5.8	1.70	11.3	1.1385E+01	.	.	6.6971E+02
SQUIRES	20	6.6	1.70	7.0	1.1385E+01	.	.	6.6971E+02
ASQUITH SL	18	7.5	1.02	.	6.9000E+00	6.9000	0.75	6.7647E+02
ANNANDALE	20	5.9	1.70	11.3	1.2000E+01	.	.	7.0588E+02
INDIAN HEAD CL	18	7.8	2.34	.	1.7800E+01	17.8000	0.65	7.6068E+02
REGINA HEAVY C	18	7.7	2.39	.	1.8200E+01	18.2000	0.70	7.6151E+02
BERMUDIAN	20	6.0	1.60	13.2	1.3700E+01	.	.	8.5625E+02

(Continued)

TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-267 (Cin.) (4-76)

Table A16. (Continued)

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
BERMUDIAN	20	6.0	1.60	13.2	1.4018E+01	.	.	8.7612E+02
BEGBROKE S L	7	7.1	1.11	.	1.0800E+01	.	.	9.7297E+02
COLTS NECK	20	4.2	1.20	7.7	1.2000E+01	.	.	1.0000E+03
TRAWSCOED SICL	8	6.2	3.69	12.0	5.0000E+01	.	.	1.3550E+03
MELFORT L	18	5.9	6.05	.	9.7700E+01	97.7000	0.77	1.6149E+03
ROSEMAUNDE SCL	8	6.7	1.76	14.0	3.5000E+01	.	.	1.9886E+03
LAKEWOOD	20	3.5	0.50	1.8	1.0815E+01	.	.	2.1630E+03
WEED RES. SL	8	7.1	1.93	11.0	4.7000E+01	.	.	2.4352E+03
LAKEWOOD	20	3.6	0.50	1.8	1.3390E+01	.	.	2.6780E+03

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table A17. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Malathion and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
COLTS NECK	20	4.5	1.20	7.7	6.9490E+00	.	.	5.7908E+02
WASHINGTON	20	6.0	2.40	11.2	1.6667E+01	.	.	6.9446E+02
WHIPPANY	20	5.7	1.90	9.4	1.3256E+01	.	.	6.9768E+02
COLTS NECK	20	4.8	1.20	7.7	8.8680E+00	.	.	7.3900E+02
LAKEWOOD	20	4.7	0.50	1.8	4.2340E+00	.	.	8.4680E+02
LAKEWOOD	20	4.5	0.50	1.8	4.2860E+00	.	.	8.5720E+02
WHIPPANY	20	5.7	1.90	9.4	1.6667E+01	.	.	8.7721E+02
SASSAFRAS	20	5.3	2.00	7.7	2.4483E+01	.	.	1.2241E+03
SASSAFRAS	20	5.1	2.00	7.7	2.6697E+01	.	.	1.3348E+03
COLLINGTON	20	5.7	2.60	12.8	3.6512E+01	.	.	1.4043E+03
WASHINGTON	20	6.1	2.40	11.2	3.4444E+01	.	.	1.4352E+03
DUTCHESS	20	5.7	2.90	12.7	4.7143E+01	.	.	1.6256E+03
ANNANDALE	20	6.2	1.70	11.3	3.3478E+01	.	.	1.9693E+03
SQUIRES	20	6.4	1.70	7.0	3.6512E+01	.	.	2.1478E+03
COLLINGTON	20	5.6	2.60	12.8	5.6667E+01	.	.	2.1795E+03
DUTCHESS	20	5.8	2.90	12.7	6.6923E+01	.	.	2.3077E+03
BERMUDIAN	20	6.4	1.60	13.2	4.0633E+01	.	.	2.5396E+03
SQUIRES	20	6.6	1.70	7.0	6.4074E+01	.	.	3.7691E+03
BERMUDIAN	20	6.4	1.60	13.2	6.6923E+01	.	.	4.1827E+03
ANNANDALE	20	6.1	1.70	11.3	7.6956E+01	.	.	4.5268E+03

Table A18. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Methyl Parathion and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
WEBSTER	42	7.3	3.87	54.7	1.3390E+01	13.3900	0.75	3.4599E+02
CECIL	42	5.6	0.90	6.8	3.9500E+00	3.9500	0.85	4.3889E+02
EUSTIS	42	5.6	0.56	5.2	2.7200E+00	2.7200	0.86	4.8571E+02
SWEENEY SCL	15	6.3	0.65	.	1.9560E+01	19.5600	1.03	3.0092E+03
HUGO GRAVELLY SL	15	5.5	0.12	.	8.8700E+00	8.8700	1.04	7.3917E+03
TIERRA CL	15	6.2	0.33	.	2.6760E+01	26.7600	1.04	8.1091E+03
ELKHORN SL	15	6.0	0.09	.	1.3700E+01	13.7000	1.04	1.5930E+04

Table A19. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Methyl Urea and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
TOLL FARM HP	8	7.4	11.70	41.0	5.6000E+00	.	.	4.7863E+01
ROSEMAUNDE SCL	8	6.7	1.76	14.0	1.0000E+00	.	.	5.6818E+01
TRAWSCOED SICL	8	6.2	3.69	12.0	2.1000E+00	.	.	5.6911E+01
GREAT HOUSE S L	8	6.3	12.00	18.0	7.2000E+00	.	.	6.0000E+01
WEED RES. SL	8	7.1	1.93	11.0	1.4000E+00	.	.	7.2539E+01

Table A20. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Metobromuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
REGINA HEAVY C	18	7.7	2.39	.	4.3000E+00	4.3000	0.83	1.7992E+02
ASQUITH SL	18	7.5	1.02	.	2.1000E+00	2.1000	0.89	2.0588E+02
WEYBURN OXBOW L	18	6.5	3.72	.	1.1100E+01	11.1000	0.64	2.9839E+02
INDIAN HEAD CL	18	7.8	2.34	.	9.4000E+00	9.4000	0.68	4.0171E+02
MELFORT L	18	5.9	6.05	.	6.1400E+01	61.4000	0.49	1.0149E+03

Table A21. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Monolinuron and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
ASQUITH SL	18	7.5	1.02	.	1.2000E+00	1.2000	0.84	1.1765E+02
WEYBURN OXBOW L	18	6.5	3.72	.	5.5000E+00	5.5000	0.80	1.4785E+02
REGINA HEAVY C	18	7.7	2.39	.	3.6000E+00	3.6000	0.80	1.5063E+02
TOLL FARM HP	8	7.4	11.70	41.0	2.1000E+01	.	.	1.7949E+02
GREAT HOUSE SL	8	6.3	12.00	18.0	2.5000E+01	.	.	2.0833E+02
INDIAN HEAD CL	18	7.8	2.34	.	5.8000E+00	5.8000	0.69	2.4786E+02
TRAWSCOED SICL	8	6.2	3.69	12.0	1.1000E+01	.	.	2.9810E+02
ROSEMAUNDE SCL	8	6.7	1.76	14.0	8.1000E+00	.	.	4.6023E+02
WEED RES. SL	8	7.1	1.93	11.0	9.6000E+00	.	.	4.9741E+02
MELFORT L	18	5.9	6.05	.	3.2400E+01	32.4000	0.69	5.3554E+02
LAKELAND SL	13	6.2	1.90	2.9	1.1000E+00	1.1000	0.70	5.7895E+01
SANDY L	29	7.1	1.93	11.0	1.5000E+00	.	.	7.7720E+01
DARK SL	29	6.3	12.00	18.0	9.5900E+00	.	.	7.9917E+01
ASQUITH SL	18	7.5	1.02	.	1.0000E+00	1.0000	1.04	9.8039E+01
CECIL LS	10	5.8	0.40	.	4.0000E-01	0.4000	1.20	1.0000E+02
CHILLUM SIL	13	4.6	2.54	7.6	3.3000E+00	3.3000	0.84	1.2992E+02
REGINA HEAVY C	18	7.7	2.39	.	3.2000E+00	3.2000	0.84	1.3389E+02
WEYBURN OXBOW L	18	6.5	3.72	.	5.8000E+00	5.8000	0.80	1.5591E+02
HAGERSTOWN SICL	13	5.5	2.48	12.5	4.0000E+00	4.0000	0.76	1.6129E+02
WEHADKEE SIL	13	5.6	1.09	10.2	1.9000E+00	1.9000	0.71	1.7431E+02
TOLL FARM HP	8	7.4	11.70	41.0	2.1800E+01	.	.	1.8632E+02
TRAWSCOED SICL	8	6.2	3.69	12.0	7.2000E+00	.	.	1.9512E+02
KEYPORT SIL	10	5.4	1.21	.	2.6000E+00	2.6000	0.68	2.1488E+02
GREAT HOUSE S L	8	6.3	12.00	18.0	2.6000E+01	.	.	2.1667E+02
INDIAN HEAD CL	18	7.8	2.34	.	5.1000E+00	5.1000	0.72	2.1795E+02
ROSEMAUNDE SCL	8	6.7	1.76	14.0	4.8000E+00	.	.	2.7273E+02
WEED RES. SL	8	7.1	1.93	11.0	5.5000E+00	.	.	2.8497E+02
MELFORT L	18	5.9	6.05	.	3.3000E+01	33.0000	0.67	5.4545E+02

EPA-287 (Cin.)
(4-76)

Table A22. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Neburon and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
TOLL FARM HP	8	7.4	11.70	41.0	2.4000E+02	.	.	2.0513E+03
GREAT HOUSE SL	8	6.3	12.00	18.0	3.2500E+02	.	.	2.7083E+03
ROSEMAUNDE SCL	8	6.7	1.76	14.0	5.8000E+01	.	.	3.2955E+03
WEED RES. SL	8	7.1	1.93	11.0	7.2000E+01	.	.	3.7306E+03
TRANSCOED SICL	8	6.2	3.69	12.0	1.3900E+02	.	.	3.7669E+03

Table A23. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for p-Chloroaniline and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
HEVERLEE	31	6.4	0.98	16.6	3.8000E+00	3.8000	0.72	3.8776E+02
HEVERLEE	31	6.6	1.44	20.6	5.8000E+00	5.8000	0.67	4.0278E+02
STAVELOT	31	3.9	2.54	5.6	1.2700E+01	12.7000	0.70	5.0000E+02
SOIGNIES	31	3.4	4.67	16.9	3.2900E+01	32.9000	0.69	7.0450E+02
MEERDAEL	31	4.0	3.57	11.7	2.9000E+01	29.0000	0.70	8.1232E+02

Table A24. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Parathion and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
SWEENEY SCL	15	6.3	0.65	.	2.2160E+01	22.1600	1.02	3.4092E+03
HUGO GRAVELLY SL	15	5.5	0.12	.	6.9000E+00	6.9000	0.99	5.7500E+03
TIERRA CL	15	6.2	0.33	.	4.0560E+01	40.5600	1.06	1.2291E+04
ELKHORN SL	15	6.0	0.09	.	1.8190E+01	18.1900	1.04	2.1151E+04

Table A25. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Phenyl Urea and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
TRAWSCOED SICL	8	6.2	3.69	12.0	2.2000E+00	.	.	5.9621E+01
TOLL FARM HP	8	7.4	11.70	41.0	8.5000E+00	.	.	7.2650E+01
RASEMAUNDE SCL	8	6.7	1.76	14.0	1.3000E+00	.	.	7.3864E+01
WEED RES. SL	8	7.1	1.93	11.0	1.6000E+00	.	.	8.2902E+01
GREAT HOUSE S L	8	6.3	12.00	18.0	1.1100E+01	.	.	9.2500E+01

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-70)

Table A26. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Picloram and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	 O.C. (%)	 C.E.C. (me/100g)	Adsorption Parameters K_D	 K	 N	 K_{oc}
ASQUITH SL	41	7.5	1.02	.	3.0000E-02	.	.	2.9412E+00
REGINA C	41	7.7	2.40	.	1.0000E-01	.	.	4.1667E+00
INDIAN HEAD L	41	7.8	2.35	.	1.0000E-01	.	.	4.2553E+00
WEYBURN OXBOW L	41	6.5	3.72	.	2.4000E-01	.	.	6.4516E+00
WOODCOCK L	26	6.1	4.44	12.9	3.0000E-01	0.3000	0.85	6.7568E+00
MELFORT L	41	5.9	6.05	.	4.9000E-01	.	.	8.0992E+00
MELFORT	2	6.5	6.00	.	4.9000E-01	.	.	8.1667E+00
WEYBURN-OXBOW	2	7.9	3.75	.	3.1000E-01	.	.	8.2667E+00
INDIAN HEAD	2	8.1	2.70	.	2.3000E-01	.	.	8.5185E+00
ASQUITH SL	2	6.9	1.04	.	9.0000E-02	.	.	8.6538E+00
WEYBURN	2	8.2	2.50	.	2.4000E-01	.	.	9.6000E+00
INDIAN HEAD C	2	8.1	2.36	.	2.4000E-01	.	.	1.0169E+01
LACOMBE	2	7.9	7.20	.	7.5000E-01	.	.	1.0417E+01
KENTWOOD SI	5	6.4	0.92	.	1.1800E-01	0.1180	0.84	1.2826E+01
EPHRATA SI	5	7.1	0.54	.	7.0000E-02	0.0700	0.60	1.2963E+01
MINAM L	26	7.3	2.19	24.4	3.0000E-01	0.3000	0.76	1.3699E+01
MINAM L	26	7.0	3.81	28.3	6.0000E-01	0.6000	0.83	1.5748E+01
PALOUSE SIL	5	5.7	1.38	.	3.1000E-01	0.3100	0.83	2.2464E+01
WOODCOCK L	26	5.8	2.48	3.6	6.0000E-01	0.6000	0.99	2.4194E+01
PALOUSE SIL	5	5.7	2.07	.	5.5300E-01	0.5530	0.82	2.6715E+01
LINNE CL	5	7.4	1.38	.	4.0900E-01	0.4090	0.74	2.9638E+01
FIDDLETOWN SIL	5	5.6	2.42	.	9.7600E-01	0.9760	0.85	4.0331E+01
WOODCOCK L	26	5.6	0.92	3.2	4.1000E-01	0.4100	1.02	4.4565E+01
KINNEY C L	26	5.0	2.88	16.1	1.6000E+00	1.6000	1.00	5.5556E+01
KINNEY C L	26	5.2	4.27	6.5	4.6000E+00	4.6000	0.84	1.0773E+02
KINNEY C L	26	5.2	1.44	8.9	2.3000E+00	2.3000	0.93	1.5972E+02

TYPING GUIDE SHEET
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table A27. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Prometone and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
LAKELAND SL	13	6.2	1.90	2.9	1.0000E+00	1.0000	0.79	5.2632E+01
CUMBERLAND SL	11	6.4	0.69	6.5	5.0000E-01	.	.	7.2464E+01
BATES SL	11	6.5	0.80	9.3	6.0000E-01	.	.	7.5000E+01
ELDON SL	11	5.9	1.73	12.9	1.3000E+00	.	.	7.5058E+01
MENFRO SL	11	5.3	1.38	9.1	1.2000E+00	.	.	8.6957E+01
BAXTER CSL	11	6.0	1.21	11.2	1.7000E+00	.	.	1.4050E+02
HAGERSTOWN SICL	13	5.5	2.48	12.5	4.3000E+00	4.3000	0.84	1.7339E+02
SARPY L	11	7.1	0.75	14.3	1.5000E+00	.	.	2.0000E+02
OSWEGO SCL	11	6.4	1.67	21.0	3.4000E+00	.	.	2.0359E+02
LINTONIA LS	11	5.3	0.34	3.2	7.0000E-01	.	.	2.0588E+02
CHILLUM SIL	13	4.6	2.54	7.6	5.4000E+00	5.4000	0.84	2.1260E+02
PUTNAM SL	11	5.3	1.09	12.3	2.8000E+00	.	.	2.5688E+02
NEWTONIA SL	11	5.2	0.92	8.8	2.4000E+00	.	.	2.6087E+02
CLARKSVILLE CSL	11	5.7	0.80	5.7	2.2000E+00	.	.	2.7500E+02
GRUNDY SCL	11	5.6	2.07	13.5	6.3000E+00	.	.	3.0435E+02
WAVERLY SL	11	6.4	1.15	12.8	3.8000E+00	.	.	3.3043E+02
WEHADKEE SIL	13	5.6	1.09	10.2	3.9000E+00	3.9000	0.77	3.5780E+02
MARSHALL SCL	11	5.4	2.42	21.3	8.8000E+00	.	.	3.6364E+02
SALIX L	11	6.3	1.21	17.9	4.6000E+00	.	.	3.8017E+02
KNOX SL	11	5.4	1.67	18.8	6.4000E+00	.	.	3.8323E+02
GERALD SL	11	4.7	1.55	11.0	6.0000E+00	.	.	3.8710E+02
SUMMIT SC	11	4.8	2.82	35.1	1.1600E+01	.	.	4.1135E+02
LINDLEY L	11	4.7	0.86	6.9	4.7000E+00	.	.	5.4651E+02
UNION SL	11	5.4	1.04	6.8	6.1000E+00	.	.	5.8654E+02
LEBANON SL	11	4.9	1.04	7.7	7.8000E+00	.	.	7.5000E+02
SHELBY L	11	4.3	2.07	20.1	2.2300E+01	.	.	1.0773E+03
WABASH C	11	5.7	1.27	40.3	1.7000E+01	.	.	1.3386E+03
MARIAN SL	11	4.6	0.80	9.9	1.4900E+01	.	.	1.8625E+03
SHARKEY C	11	5.0	1.44	28.2	5.5200E+01	.	.	3.8333E+03

Table A28. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Prometryne and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
WEHADKEE SIL	13	5.6	1.09	10.2	6.2000E-01	0.6200	0.84	5.6881E+01
LAKELAND SL	13	6.2	1.90	2.9	1.9000E+00	1.9000	0.88	1.0000E+02
COBB S	30	7.3	0.34	3.8	6.6000E-01	0.6600	0.77	1.9412E+02
BATES SL	11	6.5	0.80	9.3	1.6000E+00	.	.	2.0000E+02
CUMBERLAND SL	11	6.4	0.69	6.5	1.4000E+00	.	.	2.0290E+02
ELDON SL	11	5.9	1.73	12.9	3.6000E+00	.	.	2.0785E+02
MENFRO SL	11	5.3	1.38	9.1	3.3000E+00	.	.	2.3913E+02
LINTONIA LS	11	5.3	0.34	3.2	9.0000E-01	.	.	2.6471E+02
SOIL 4	32	.	3.82	26.9	1.0400E+01	.	.	2.7225E+02
SOIL 5	32	.	13.61	31.2	3.9800E+01	.	.	2.9243E+02
OSWEGO SCL	11	6.4	1.67	21.0	5.0000E+00	.	.	2.9940E+02
SOIL 2	32	.	1.56	10.3	5.0000E+00	.	.	3.2051E+02
SOIL 3	32	.	1.76	22.3	5.7000E+00	.	.	3.2386E+02
SOIL 6	32	.	19.98	83.1	6.5400E+01	.	.	3.2733E+02
PUTNAM SL	11	5.3	1.09	12.3	3.8000E+00	.	.	3.4862E+02
BAXTER CSL	11	6.0	1.21	11.2	4.3000E+00	.	.	3.5537E+02
NEWTONIA SL	11	5.2	0.92	8.8	3.5000E+00	.	.	3.8043E+02
SARPY L	11	7.1	0.75	14.3	2.9000E+00	.	.	3.8667E+02
HAGERSTOWN SICL	13	5.5	2.48	12.5	1.0300E+01	10.3000	0.84	4.1532E+02
GRUNDY SCL	11	5.6	2.07	13.5	9.2000E+00	.	.	4.4444E+02
PORT SIC	30	6.3	1.04	17.9	4.9000E+00	4.9000	0.76	4.7115E+02
KNOX SL	11	5.4	1.67	18.8	8.4000E+00	.	.	5.0299E+02
WAVERLY SL	11	6.4	1.15	12.8	5.8000E+00	.	.	5.0435E+02

(Continued)

Table A28. (Continued)

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
CHILLUM SIL	13	4.6	2.54	7.6	1.2900E+01	12.9000	0.86	5.0787E+02
MARSHALL SCL	11	5.4	2.42	21.3	1.2300E+01	.	.	5.0826E+02
SALIX L	11	6.3	1.21	17.9	6.4000E+00	.	.	5.2893E+02
GERALD SL	11	4.7	1.55	11.0	9.4000E+00	.	.	6.0645E+02
SOIL 1	32	.	0.51	10.6	3.1000E+00	.	.	6.0784E+02
BREWER CL	30	5.8	1.61	13.5	9.9500E+00	9.9500	0.83	6.1801E+02
CLARKSVILLE CSL	11	5.7	0.80	5.7	5.1000E+00	.	.	6.3750E+02
UNION SL	11	5.4	1.04	6.8	8.6000E+00	.	.	8.2692E+02
KEBABIB SL	11	4.9	1.04	7.7	9.0000E+00	.	.	8.6538E+02
LINDLEY L	11	4.7	0.86	6.9	7.9000E+00	.	.	9.1860E+02
SHELBY L	11	4.3	2.07	20.1	2.2100E+01	.	.	1.0676E+03
WABASH C	11	5.7	1.27	40.3	1.7300E+01	.	.	1.3622E+03
MARIAN SL	11	4.6	0.80	9.9	1.4200E+01	.	.	1.7750E+03
COBB	30	5.3	1.21	9.0	2.8900E+01	28.9000	0.79	2.3884E+03
SHARKEY C	11	5.0	1.44	28.2	4.3400E+01	.	.	3.0139E+03

EPA-287 (Cin.)
(4-76)

Table A29. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Propazine and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
LINTONIA LS	11	5.3	0.34	3.2	1.0000E-01	.	.	2.9412E+01
LAKELAND SL	13	6.2	1.90	2.9	8.0000E-01	0.8000	0.91	4.2105E+01
BATES SL	11	6.5	0.80	9.3	7.0000E-01	.	.	8.7500E+01
SOIL 4	32	.	3.82	26.9	3.5000E+00	.	.	9.1623E+01
PUTNAM SL	11	5.9	1.09	12.3	1.1000E+00	.	.	1.0092E+02
CUMBERLAND SL	11	6.4	0.69	6.5	7.0000E-01	.	.	1.0145E+02
SOIL 6	32	.	19.98	83.1	2.0500E+01	.	.	1.0260E+02
ELDON SL	11	5.9	1.73	12.9	1.8000E+00	.	.	1.0393E+02
OSWEGO SCL	11	6.4	1.67	21.0	1.9000E+00	.	.	1.1377E+02
GERALD SL	11	4.7	1.55	11.0	1.8000E+00	.	.	1.1613E+02
SUMMIT SC	11	4.8	2.82	35.1	3.4000E+00	.	.	1.2057E+02
MARSHALL SCL	11	5.4	2.42	21.3	3.0000E+00	.	.	1.2397E+02
MENFRO SL	11	5.3	1.38	9.1	1.8000E+00	.	.	1.3043E+02
SHELBY L	11	4.3	2.07	20.1	2.8000E+00	.	.	1.3527E+02
GRUNDY SCL	11	5.6	2.07	13.5	2.8000E+00	.	.	1.3527E+02
SOIL 5	32	.	13.61	31.2	1.9700E+01	.	.	1.4475E+02
WEHADKEE SIL	13	5.6	1.09	10.2	1.6000E+00	1.6000	0.99	1.4679E+02
HAGERSTOWN SICL	13	5.5	2.48	12.5	3.7000E+00	3.7000	0.94	1.4919E+02
NEWTONIA SL	11	5.2	0.92	8.8	1.4000E+00	.	.	1.5217E+02
BAXTER CSL	11	6.0	1.21	11.2	1.9000E+00	.	.	1.5702E+02
SALIX L	11	6.3	1.21	17.9	1.9000E+00	.	.	1.5702E+02

(Continued)

Table A29. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
SARPY L	11	7.1	0.75	14.3	1.2000E+00	.	.	1.6000E+02
KNOX SL	11	5.4	1.67	18.8	2.7000E+00	.	.	1.6168E+02
SOIL 3	32	.	1.76	22.3	3.0000E+00	.	.	1.7045E+02
WAVERLY SL	11	6.4	1.15	12.8	2.0000E+00	.	.	1.7391E+02
SOIL 1	32	.	0.51	10.6	9.0000E-01	.	.	1.7647E+02
CHILLUM SIL	13	4.6	2.54	7.6	4.6000E+00	4.6000	0.96	1.8110E+02
SOIL 2	32	.	1.56	10.3	3.0000E+00	.	.	1.9231E+02
LEBANON SL	11	4.9	1.04	7.7	2.0000E+00	.	.	1.9231E+02
SHARKEY C	11	5.0	1.44	28.2	3.0000E+00	.	.	2.0833E+02
LEBANON SL	11	4.9	1.04	7.7	2.2000E+00	.	.	2.1154E+02
UNION SL	11	5.4	1.04	6.8	2.4000E+00	.	.	2.3077E+02
WABASH C	11	5.7	1.27	40.3	3.1000E+00	.	.	2.4409E+02
LINDLEY L	11	4.7	0.86	6.9	2.2000E+00	.	.	2.5581E+02
MARIAN SL	11	4.6	0.80	9.9	2.1000E+00	.	.	2.6250E+02
CLARKSVILLE CSL	11	5.7	0.80	5.7	2.1000E+00	.	.	2.6250E+02

EPA-287 (Cin.)
(4-78)

Table A30. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Simazine and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
IREDELL C	12	5.6	6.17	20.9	1.5790E+00	.	.	2.5592E+01
GREENFIELD SL	4	7.3	2.77	15.8	9.3000E-01	.	.	3.3574E+01
PARK GRASS 13D	44	4.7	2.80	.	1.0000E+00	.	.	3.5714E+01
LAKELAND SL	12	6.2	1.88	2.9	6.8200E-01	.	.	3.6277E+01
HANFORD SL	4	6.2	1.90	12.4	6.9000E-01	.	.	3.6316E+01
MONTALTO C	12	5.9	0.86	8.4	3.1900E-01	.	.	3.7093E+01
TIFTON LS	12	4.9	0.56	2.4	2.0800E-01	.	.	3.7143E+01
PARK GRASS 13D	44	4.8	1.80	.	7.0000E-01	.	.	3.8889E+01
EXETER SL	4	6.7	1.32	12.8	5.6000E-01	.	.	4.2424E+01
YOLO SL	4	6.9	2.59	20.4	1.1200E+01	.	.	4.3243E+01
PARK GRASS 13D	44	4.8	4.50	.	2.0000E+00	.	.	4.4444E+01
RAMONA SL	4	6.7	1.38	10.4	6.1500E-01	.	.	4.4565E+01
PARK GRASS 3A	44	7.0	5.60	.	2.5000E+00	.	.	4.4643E+01
HANFORD LS	4	7.2	1.27	9.5	5.9000E-01	.	.	4.6457E+01
LAKELAND SL	13	6.2	1.90	2.9	9.0000E-01	0.9000	0.75	4.7368E+01
YOLO SL	4	7.0	2.30	21.2	1.0900E+00	.	.	4.7391E+01
BAUTISTA SL	4	7.2	1.03	14.2	4.9000E-01	.	.	4.7573E+01
PARK GRASS 13A	44	6.6	2.10	.	1.0000E+00	.	.	4.7619E+01
BROADBALK	44	6.6	1.20	.	6.0000E-01	.	.	5.0000E+01
PARK GRASS 3A	44	6.8	2.40	.	1.2000E+00	.	.	5.0000E+01
PARK GRASS 3A	44	6.9	3.60	.	1.8000E+00	.	.	5.0000E+01
GREENFIELD SL	4	6.5	1.38	12.6	6.9000E-01	.	.	5.0000E+01

(Continued)

TYPING GUIDE SHEET

Table A30. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
BROADBALK	44	7.9	1.00	.	5.0000E-01	.	.	5.0000E+01
FALLBROOK FSL	4	6.4	2.77	19.7	1.4100E+00	.	.	5.0903E+01
PARK GRASS 14A	44	6.9	5.50	.	2.8000E+00	.	.	5.0909E+01
PARK GRASS 13A	44	6.5	3.50	.	1.8000E+00	.	.	5.1429E+01
PARK GRASS 13A	44	6.8	6.00	.	3.1000E+00	.	.	5.1667E+01
BROADBALK	44	7.5	2.90	.	1.5000E+00	.	.	5.1724E+01
COACHELLA SL	4	7.1	1.03	11.8	5.4000E-01	.	.	5.2427E+01
HANFORD SL	4	6.3	2.82	18.1	1.4800E+00	.	.	5.2482E+01
INDIO L	4	7.2	1.32	15.1	7.1000E-01	.	.	5.3788E+01
RAMONA SL	4	5.9	1.78	15.2	9.7000E-01	.	.	5.4494E+01
HANFORD SL	4	6.0	1.38	11.0	7.8000E-01	.	.	5.6522E+01
PARK GRASS 3D	44	5.1	5.30	.	3.0000E+00	.	.	5.6604E+01
RAMONA SL	4	6.6	0.51	9.5	2.9000E-01	.	.	5.6863E+01
GREENFIELD SL	4	6.4	2.07	16.4	1.1800E+00	.	.	5.7005E+01
DOCOR ADOBE CL	4	7.2	2.13	34.6	1.2200E+00	.	.	5.7277E+01
PARK GRASS 14A	44	6.9	3.30	.	1.9000E+00	.	.	5.7576E+01
HANFORD SL	4	6.4	1.55	12.4	9.0000E-01	.	.	5.8065E+01
HANFORD LS	4	5.8	1.15	9.6	6.7000E-01	.	.	5.8261E+01
BENEVOLA SIC	12	7.7	2.70	19.5	1.5790E+00	.	.	5.8481E+01
RUSTON SL	12	5.1	1.05	3.4	6.1800E-01	.	.	5.8857E+01
SAN JOAQUIN SL	4	7.2	0.69	8.6	4.1000E-01	.	.	5.9420E+01
PARK GRASS 3D	44	5.1	3.10	.	1.9000E+00	.	.	6.1290E+01
BERKLEY SIC	12	7.1	4.63	33.7	2.9360E+00	.	.	6.3413E+01
SAN JOAQUIN L	4	5.1	1.44	11.2	9.2000E-01	.	.	6.3889E+01
ELKHORN LS	4	6.7	1.67	13.2	1.1000E+00	.	.	6.5868E+01

(Continued)

EPA-287 (Cin.)
(4-76)

Table A30. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
PORTERVILLE ADOBE C	4	7.3	1.90	37.6	1.2700E+00	.	.	6.6842E+01
INDIO L	4	7.2	1.21	13.4	8.1000E-01	.	.	6.6942E+01
HAGERSTOWN SICL	12	5.5	2.48	12.5	1.6670E+00	.	.	6.7218E+01
BENEVOLA C	12	7.6	1.30	20.1	8.8200E-01	.	.	6.7846E+01
YOLO SL	4	7.0	1.32	17.0	9.0000E-01	.	.	6.8182E+01
CECIL SC	12	5.3	1.09	3.6	7.4700E-01	.	.	6.8532E+01
ELKHORN LS	4	7.0	1.27	11.6	8.8000E-01	.	.	6.9291E+01
YOLO L	4	5.8	1.61	22.1	1.1200E+00	.	.	6.9565E+01
HANFORD LS	4	6.5	0.86	7.5	6.0000E-01	.	.	6.9767E+01
EXETER LS	4	5.8	1.50	14.7	1.0700E+00	.	.	7.1333E+01
PARK GRASS 3D	44	5.3	2.10	.	1.5000E+00	.	.	7.1429E+01
YOLO SL	4	6.9	1.32	17.1	9.6000E-01	.	.	7.2727E+01
VISTA LS	4	6.5	0.86	10.0	6.6000E-01	.	.	7.6744E+01
PARK GRASS 11/2D	44	3.8	1.80	.	1.4000E+00	.	.	7.7778E+01
OOSTER SIL	12	4.7	1.31	6.3	1.0240E+00	.	.	7.8168E+01
YOLO L	4	7.2	1.78	27.4	1.4300E+00	.	.	8.0337E+01
VISTA SL	4	6.2	0.75	14.2	6.1000E-01	.	.	8.1333E+01
SAN JOAQUIN L	4	6.6	1.15	16.7	9.4000E-01	.	.	8.1739E+01
BERKLEY C	12	7.3	0.99	34.4	8.1400E-01	.	.	8.2222E+01
PARK GRASS 14A	44	6.9	1.80	.	1.5000E+00	.	.	8.3333E+01
SAN JOAQUIN L	4	5.6	1.15	14.0	9.6000E-01	.	.	8.3478E+01
HAGERSTOWN SICL	12	7.5	1.30	8.8	1.0980E+00	.	.	8.4462E+01
GARLAND C	12	7.7	0.65	23.2	5.5600E-01	.	.	8.5538E+01
THURLOW CL	12	7.7	1.25	21.6	1.0980E+00	.	.	8.7840E+01
PARK GRASS 11/2D	44	3.6	3.30	.	2.9000E+00	.	.	8.7879E+01
AIKEN L	4	5.2	2.94	20.6	2.5900E+00	.	.	8.8095E+01
YOLO CL	4	7.2	1.27	27.8	1.1500E+00	.	.	9.0551E+01

(Continued)

EPA-287 (Cin.)
(4-76)

Table A30. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{OC}
SAN JOAQUIN CL	4	7.4	1.21	20.8	1.1000E+00	.	.	9.0909E+01
BARNES CL	12	7.4	3.98	33.8	3.6210E+00	.	.	9.0980E+01
DUNUBA FSL	4	6.2	0.46	6.6	4.2000E-01	.	.	9.1304E+01
CHESTER L	12	4.9	1.67	5.2	1.5790E+00	.	.	9.4551E+01
ASCALON SCL	12	7.3	0.85	12.7	8.1400E-01	.	.	9.5765E+01
VISTA SL	4	6.8	0.69	13.2	6.9000E-01	.	.	1.0000E+02
PORTERVILLE ADOBE CL	4	6.4	0.75	18.1	7.5000E-01	.	.	1.0000E+02
STERLING CL	12	7.7	0.94	22.5	9.5200E-01	.	.	1.0128E+02
CHILLUM SIL	12	4.6	2.54	7.6	2.5760E+00	.	.	1.0142E+02
PANOCHEL	4	7.5	0.57	20.2	5.8000E-01	.	.	1.0175E+02
TRIPP L	12	7.6	0.86	14.7	8.8200E-01	.	.	1.0256E+02
HOVEY ADOBE L	4	6.6	2.25	49.8	2.3300E+00	.	.	1.0356E+02
SORRENTO FSL	4	6.9	1.09	16.1	1.1500E+00	.	.	1.0550E+02
BAUTISTA LS	4	6.4	0.28	5.5	3.0000E-01	.	.	1.0714E+02
PARK GRASS 11/2D	44	3.7	10.90	.	1.1900E+01	.	.	1.0917E+02
TOLEDO SIC	12	5.5	2.80	29.8	3.0640E+00	.	.	1.0943E+02
LAS POSAS SL	4	7.3	1.09	11.8	1.2000E+00	.	.	1.1009E+02
WEHADKEE SIL	12	5.6	1.11	10.2	1.2500E+00	.	.	1.1261E+02
IREDELL SIL	12	5.4	3.04	17.0	3.4750E+00	.	.	1.1431E+02
YOLO CL	4	6.8	2.07	31.0	2.3700E+00	.	.	1.1449E+02
MANZANITA CL	4	5.9	1.21	13.8	1.4200E+00	.	.	1.1736E+02
YOLO L	4	6.6	1.73	17.8	2.0500E+00	.	.	1.1850E+02
BATES SL	11	6.5	0.80	9.3	1.0000E+00	.	.	1.2500E+02
SAN JOAQUIN SCL	4	6.1	0.75	15.2	9.5000E-01	.	.	1.2667E+02
VISTA SL	4	6.4	0.86	12.6	1.1000E+00	.	.	1.2791E+02

(Continued)

Table A30. (Continued)

Soil	Article* No.	Soil Properties pH	O.C. (%)	C.E.C. (me/100g)	Adsorption Parameters K_D	K	N	K_{oc}
CHILLUM SIL	13	4.6	2.54	7.6	3.3000E+00	3.3000	0.84	1.2992E+02
MARIAN SL	11	4.6	0.80	9.9	3.5000E+00	.	.	4.3750E+02
WABASH C	11	5.7	1.27	40.3	6.0000E+00	.	.	4.7244E+02
SHARKEY C	11	5.0	1.44	28.2	7.0000E+00	.	.	4.8611E+02
DUNDEE SICL	12	5.0	0.96	18.1	6.6280E+00	.	.	6.9042E+02
CHINO SL	4	7.4	2.36	14.2	3.6000E+01	.	.	1.5254E+03
CAJON L	4	6.2	1.27	14.6	1.6500E+00	.	.	1.2992E+02
DIABLO SCL	4	6.1	0.69	35.8	9.1000E-01	.	.	1.3188E+02
HAGERSTOWN SICL	13	5.5	2.48	12.5	3.3000E+00	3.3000	0.78	1.3306E+02
SUPERSTITION LS	4	7.2	0.23	5.6	3.1000E-01	.	.	1.3478E+02
BELTSVILLE SIL	12	4.3	1.40	4.2	1.9440E+00	.	.	1.3916E+02
WYMAN CL	4	6.4	1.78	32.0	2.5200E+00	.	.	1.4157E+02
WYMAN L	4	6.6	1.21	15.4	1.7800E+00	.	.	1.4711E+02
CROSBY SIL	12	4.8	1.90	11.5	2.8130E+00	.	.	1.4805E+02
STATEN PEATY L	4	6.9	14.00	72.1	2.1200E+01	.	.	1.5143E+02
ELDON SL	11	5.9	1.73	12.9	2.9000E+00	.	.	1.6744E+02
CUMBERLAND SL	11	6.4	0.69	6.5	1.2000E+00	.	.	1.7391E+02
CLARKSVILLE CSL	11	5.7	0.80	5.7	1.4000E+00	.	.	1.7500E+02
MENFRO SL	11	5.3	1.38	9.1	2.5000E+00	.	.	1.8116E+02
BRENTWOOD C	4	6.1	1.67	30.8	3.0300E+00	.	.	1.8144E+02
BAXTER CSL	11	6.0	1.21	11.2	2.3000E+00	.	.	1.9008E+02
TRUCKTON SL	12	7.0	0.25	4.4	4.9400E-01	.	.	1.9760E+02
PUTNAM SL	11	5.3	1.09	12.3	2.2000E+00	.	.	2.0183E+02
RINCON L	4	5.8	1.78	25.2	3.8300E+00	.	.	2.1517E+02

(Continued)

Table A30. (Continued)

Soil	Article* No.	Soil Properties pH	 O.C. (%)	 C.E.C. (me/100g)	Adsorption Parameters K_D	 K	 N	 K_{oc}
CHRISTIANA L	12	4.4	0.57	5.6	1.2500E+00	.	.	2.1930E+02
COLOMBIA VFSL	4	7.3	0.86	15.0	1.9900E+00	.	.	2.3140E+02
YOLO CL	4	6.1	2.13	31.0	4.9500E+00	.	.	2.3239E+02
OSWEGO SCL	11	6.4	1.67	21.0	3.9000E+00	.	.	2.3353E+02
COLUMBIA CL	4	6.8	1.38	26.5	3.2300E+00	.	.	2.3406E+02
YOLO L	4	7.3	1.03	24.0	2.5300E+00	.	.	2.4563E+02
SHELBY L	11	4.3	2.07	20.1	5.1000E+00	.	.	2.4638E+02
WEHADKEE SIL	13	5.6	1.09	10.2	2.7000E+00	2.7000	0.76	2.4771E+02
NORFOLK SL	12	5.1	0.08	0.2	2.0800E-01	.	.	2.6000E+02
SHARKEY C	12	6.2	2.25	40.2	5.8700E+00	.	.	2.6089E+02
SARPY L	11	7.1	0.75	14.3	2.0000E+00	.	.	2.6667E+02
LEBANON SL	11	4.9	1.04	7.7	2.8000E+00	.	.	2.6923E+02
WAVERLY SL	11	6.4	1.15	12.8	3.1000E+00	.	.	2.6957E+02
GERALD SL	11	4.7	1.55	11.0	4.2000E+00	.	.	2.7097E+02
SUMMIT SC	11	4.8	2.82	35.1	7.9000E+00	.	.	2.8014E+02
SALIX L	11	6.3	1.21	17.9	3.5000E+00	.	.	2.8926E+02
LINTONIA LS	11	5.3	0.34	3.2	1.0000E+00	.	.	2.9412E+02
MARSHALL SCL	11	5.4	2.42	21.3	7.2000E+00	.	.	2.9752E+02
LINDLEY L	11	4.7	0.86	6.9	2.6000E+00	.	.	3.0233E+02
KNOX SL	11	5.4	1.67	18.8	5.1000E+00	.	.	3.0539E+02
BOSKET SIL	12	5.8	0.57	8.4	1.7570E+00	.	.	3.0825E+02
GRUNDY SCL	11	5.6	2.07	13.5	6.5000E+00	.	.	3.1401E+02
NEWTONIA SL	11	5.2	0.92	8.8	3.0000E+00	.	.	3.2609E+02
UNION SL	11	5.4	1.04	6.8	3.8000E+00	.	.	3.6538E+02

Table A33. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for trans-telone and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
PEATY S	22	.	10.39	.	7.7000E+01	.	.	7.4110E+02
HUMUS S	22	.	3.17	.	2.4000E+01	.	.	7.5710E+02
PEATY S	22	.	10.39	.	1.3000E+02	.	.	1.2512E+03
HUMUS S	22	.	3.17	.	4.0000E+01	.	.	1.2618E+03
PEATY S	22	.	10.39	.	2.2000E+02	.	.	2.1174E+03
HUMUS S	22	.	3.17	.	6.8000E+01	.	.	2.1451E+03

Table A34. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for Trithion and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
SWEENEY SCL	15	6.3	0.65	.	5.4560E+01	54.5600	0.88	8.3938E+03
TIERRA CL	15	6.2	0.33	.	9.8650E+01	98.6500	0.88	2.9894E+04
HUGO GRAVELLY SL	15	5.5	0.12	.	6.2800E+01	62.8000	1.00	5.2333E+04
ELKHORN SL	15	6.0	0.09	.	8.2300E+01	82.3000	1.00	9.5698E+04

EPA-287 (Cin.)
(4-76)

Preceding page blank

Table A35. Adsorption Isotherm Parameters (K,N,K_D and K_{OC}) for 2,4-D acid and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
REGINA HC	17	7.7	2.39	.	1.9000E-01	1.2200	.	7.9498E+00
WEYBURN OXBOW L	17	6.5	3.72	.	4.5000E-01	0.4500	1.05	1.2097E+01
REGINA C	41	7.7	2.40	.	3.1000E-01	.	.	1.2917E+01
ASQUITH SL	41	7.5	1.02	.	1.4000E-01	.	.	1.3725E+01
MELFORT L	17	5.9	6.05	.	9.9000E-01	0.9900	1.00	1.6364E+01
WEYBURN OXBOW L	41	6.5	3.72	.	6.1000E-01	.	.	1.6398E+01
INDIAN HEAD L	41	7.8	2.35	.	4.4000E-01	.	.	1.8723E+01
INDIAN HEAD L	17	7.8	2.34	.	5.3000E-01	0.5300	0.97	2.2650E+01
MELFORT L	41	5.9	6.05	.	3.3800E+00	.	.	5.5868E+01

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table A36. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for 2,4-D amine and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
CECIL	42	5.6	0.90	6.8	6.5000E-01	0.6500	0.83	7.2222E+01
WEBSTER	42	7.3	3.87	54.7	4.6200E+00	4.6200	0.70	1.1938E+02
EUSTIS	42	5.6	0.56	5.2	7.6000E-01	0.7600	0.73	1.3571E+02

Table A37. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for 2,4,5-T and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
EPHRATA SL	35	7.5	0.80	.	3.1000E-01	.	.	3.8750E+01
ORDINANCE SL	35	6.6	3.66	.	2.4000E+00	.	.	6.5574E+01
GLENDALE SICL	35	8.5	0.53	.	4.9000E-01	.	.	9.2453E+01
PALOUSE SIL	35	6.5	2.43	.	3.0000E+00	.	.	1.2346E+02

Table A38. Adsorption Isotherm Parameters (K,N,K_D and K_{oc}) for Denobil and selected soil properties compiled from the literature.

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{oc}
CROGHAN LFS	21	4.2	3.75	.	2.2000E+00	.	.	5.8667E+01
CROGHAN LFS	21	4.4	1.73	.	1.6000E+00	.	.	9.2379E+01
CAMRODEN SIL	21	4.6	1.15	.	1.1000E+00	.	.	9.5652E+01
EMPEYVILLE SIL	21	4.5	4.33	.	4.5000E+00	.	.	1.0393E+02
LACKAWANNA SIL	21	4.6	5.54	.	6.0000E+00	.	.	1.0830E+02
COVINGTON SIC	21	5.7	5.30	.	6.7000E+00	.	.	1.2642E+02
CAMRODEN SIL	21	4.6	4.73	.	6.6000E+00	.	.	1.3953E+02
CROGHAN LFS	21	5.7	2.65	.	3.7000E+00	.	.	1.3962E+02
EMPEYVILLE SIL	21	4.9	5.54	.	7.8000E+00	.	.	1.4079E+02
CROGHAN LFS	21	4.6	0.28	.	4.0000E-01	.	.	1.4286E+02
HOWARD GRL	21	4.6	3.06	.	4.4000E+00	.	.	1.4379E+02
AMENIA SIL	21	6.2	3.34	.	5.0000E+00	.	.	1.4970E+02
MARDIN SIL	21	5.9	2.88	.	4.5000E+00	.	.	1.5625E+02
VERGENNES SIL	21	4.6	2.80	.	4.5000E+00	.	.	1.6071E+02
TROY GRSIL	21	3.8	2.42	.	3.9000E+00	.	.	1.6116E+02
VERGENNES C	21	4.8	2.54	.	4.1000E+00	.	.	1.6142E+02
LIMA GRSI	21	6.3	2.59	.	4.2000E+00	.	.	1.6216E+02
EMPEYVILLE SIL	21	4.5	1.04	.	1.7000E+00	.	.	1.6346E+02
WILLIAMSON SIL	21	3.9	2.54	.	4.3000E+00	.	.	1.6929E+02
GRANBY FSL	21	6.8	3.00	.	5.1000E+00	.	.	1.7000E+02
SODUS GRL	21	4.8	3.06	.	5.3000E+00	.	.	1.7320E+02
VERGENNES SIL	21	4.6	0.75	.	1.3000E+00	.	.	1.7333E+02
VERGENNES SIL	21	5.9	0.75	.	1.3000E+00	.	.	1.7333E+02

(Continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
3/8"
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table A38. (Continued)

Soil	Article* No.	Soil Properties			Adsorption Parameters			
		pH	O.C. (%)	C.E.C. (me/100g)	K_D	K	N	K_{OC}
AMENIA SIL	21	6.4	0.69	.	1.2000E+00	.	.	1.7391E+02
VERGENNES SIL	21	4.9	0.34	.	6.0000E-01	.	.	1.7647E+02
COLONIE LFS	21	5.0	0.92	.	1.9000E+00	.	.	2.0652E+02
COVINGTON SIC	21	6.5	0.57	.	1.3000E+00	.	.	2.2807E+02
CROGHAN LFS	21	4.8	0.11	.	3.0000E-01	.	.	2.6087E+02
COVINGTON SIC	21	6.7	0.40	.	1.3000E+00	.	.	3.2500E+02
AMENIA SIL	21	7.1	0.28	.	1.2000E+00	.	.	4.2857E+02
EMPEYVILLE SIL	21	4.6	0.17	.	9.0000E-01	.	.	5.2023E+02
CROGHAN LFS	21	4.6	0.11	.	6.0000E-01	.	.	5.2174E+02
AMENIA SIL	21	7.4	0.11	.	8.0000E-01	.	.	6.9565E+02
CAMRODEN SIL	21	5.6	0.23	.	1.9000E+00	.	.	8.2609E+02

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

Table A39. Article number used in Table A1-A38 and the corresponding literature citation.

Article No. Used in Tables	Reference	Article No. used in Tables	Reference
1	Graham-Bryce, 1967	24	Konrad and Chesters, 1969
2	Grover, 1971	25	McGlamery and Slife, 1966
3	Grover, 1974	26	Gaynor and Volk, 1976
4	Day et al., 1968	27	Burnside and Lavy, 1966
5	Farmer and Aochi, 1974	28	Geissbuhler et al., 1963
6	Liu et al., 1970	29	Hance, 1967
7	Grover and Hance, 1969	30	Murray et al., 1975
8	Hance, 1965	31	van Bladel and Moreale, 1977
9	Schliebe et al., 1965	32	Walker and Crawford, 1970
10	Rhodes et al., 1970	33	Furmidge and Osgerby, 1967
11	Talbert and Fletchall, 1965	34	Talbert et al., 1964
12	Harris and Sheets, 1965	35	O'Connor and Anderson, 1974
13	Harris, 1966	36	Wildung et al., 1968
14	Haron et al., 1967	37	Koren et al., 1969
15	King and McCarty, 1967	38	Obien and Green, 1969, and Green and Obien, 1969
16	Colbert et al., 1975		
17	Grover and Smith, 1974	39	Kay and Elrick, 1967
18	Grover, 1975	40	Majka and Lavy, 1977
19	Dao and Lavy, 1978	41	Grover, 1977
20	McNamara and Toth, 1970	42	Rao and Davidson, 1979
21	Briggs and Dawson, 1970	43	Robert and Wilson, 1965
22	Liestra, 1970	44	Williams, 1968
23	Shim et al., 1970	45	Jamet and Piedallu, 1975.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-297 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

APPENDIX B

Tables of Pesticide Transformation Rate Coefficients

6-1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table B1. Solvent extractable 2,4-D disappearance rates in laboratory incubated soils under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
1.4x10^{-1}	4.79	--	3.3	15.5	22	--	Altom and Stritzke, 1973
1.7x10^{-1}	4.79	--	2.8	16.5	22	--	Ibid
1.7x10^{-1}	4.79	--	3.8	18.5	22	--	Ibid
2.8x10^{-2}	2.5	7.2	1.91	12.6	26	6.9	Foster and McKercher, 1973
3.1x10^{-2}	2.5	7.6	3.36	15.0	26	10.0	Ibid
7.7x10^{-2}	2.5	7.8	1.84	54.5	22	16.7	Ibid
5.6x10^{-2}	2.5	6.2	6.78	53.0	26	16.1	Ibid
5.2x10^{-2}	2.5	7.5	2.85	25.0	26	15.0	Ibid
3.9x10^{-2}	2.5	7.6	2.38	24.5	26	11.9	Ibid
2.4x10^{-2}	2.5	7.2	1.91	12.6	26	13.8	Yoshida and Castro, 1975
2.2x10^{-2}	2.5	7.6	3.36	15.0	26	20.0	Ibid
6.7x10^{-2}	2.5	7.8	1.84	54.5	26	33.4	Ibid
5.3x10^{-2}	2.5	6.2	6.78	53.0	26	32.1	Ibid
5.1x10^{-2}	2.5	7.5	2.85	25.0	26	29.9	Ibid
3.4x10^{-2}	2.5	7.6	2.38	24.5	26	23.8	Ibid
7.9x10^{-2}	20	6.6	2.0	--	30	80% of FC*	Yoshida and Castro, 1975
2.1x10^{-2}	20	4.7	3.2	--	30	80% of FC*	Ibid

*FC is "field-capacity" soil-water content.

Table B2. Solvent extractable 2,4-D disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
6.4x10^{-2}	4.5	--	--	--	--	--	0-5	Radosevich and Winterlin, 1977
9.6x10^{-2}	7.8	5.8	2.6	25	5.3	--	0-10	Stewart and Gaul, 1977
4.6x10^{-2}	15.7	5.8	2.6	25	5.3	--	0-10	Ibid
7.0x10^{-2}	31.4	5.8	2.6	25	5.3	--	0-10	Ibid
1.0x10^{-1}	5.6	5.8	2.6	25	5.3	--	0-10	Ibid
8.3x10^{-2}	11.2	5.8	2.6	25	5.3	--	0-10	Ibid
6.5x10^{-2}	22.4	5.8	2.6	25	5.3	--	0-10	Ibid
4.5x10^{-1}	11.2	5.6	2.9	26	13.5-23	12.5-23.3	0-24	Wilson and Cheng, 1976
>0.7	11.2	5.6	2.9	26	13.5-23	12.5-23.3	0-24	Ibid
>0.7	1.1	5.6	2.9	26	13.5-23	12.5-23.3	0-24	Ibid
>0.7	1.1	5.6	2.9	26	13.5-23	12.5-23.3	0-24	Ibid
2.2x10^{-1}	11.2	5.6	2.9	26	13.5-23	12.5-23.3	0-24	Ibid

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Table B3. Mineralization rates of ^{14}C-ring labeled 2,4-D in soils under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
4.7×10^{-2}	50	7.3	3.9	18.4	23	30	Ou, et al., 1978
2.8×10^{-2}	50	7.3	3.9	18.4	23	30	Ibid
5.2×10^{-2}	1.6	5.6	3.2	25	25	22	Wilson and Cheng, 1978
5.5×10^{-2}	1.6	5.6	3.2	25	25	22	Ibid
6.3×10^{-2}	16	5.6	3.2	25	25	22	Ibid
5.8×10^{-2}	16	5.6	3.2	25	25	22	Ibid

Table B4. Solvent extractable 2,4,5-T disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
2.9×10^{-2}	4.79	--	3.3	15.5	22	--	Altom and Stritzke, 1973
5.0×10^{-2}	4.79	--	2.8	16.5	22	--	Ibid
3.3×10^{-2}	4.79	--	3.8	18.5	22	--	Ibid
1.2×10^{-2}	2.5	7.6	2.38	24.5	26	23.8	Foster and McKercher, 1973
3.9×10^{-2}	10	6.6	2.0	--	--	--	Yoshida and Castro, 1975
1.1×10^{-2}	10	4.7	3.2	--	--	--	Ibid

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Table B5. Solvent extractable 2,4-5-T disappearance rates under field conditions.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
7.4x10^{-2}	4.5	--	--	--	--	--	0-5	Radosevich and Winterlin, 1977
4.0x10^{-2}	7.8	5.8	2.6	25	5.3	--	0-10	Stewart and Gaul, 1977
1.5x10^{-2}	15.7	5.8	2.6	25	5.3	--	0-10	Ibid
9.9x10^{-3}	31.4	5.8	2.6	25	5.3	--	0-10	Ibid

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

Table B6. Solvent extractable atrazine disappearance rates under field conditions.

k_1 (day^{-1})	Concentration (kg/ha)	PH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
3.8×10^{-2}	1.1	6.3	2.2	30.8	--	25.8	0-15	Hall and Hartwig, 1978
3.4×10^{-2}	2.2	6.3	2.2	30.8	--	25.8	0-15	Ibid
2.7×10^{-2}	4.5	6.3	2.2	30.8	--	25.8	0-15	Ibid
4.8×10^{-2}	9.0	6.3	2.2	30.8	--	25.8	0-15	Ibid
1.3×10^{-2}	4.5	5.3	1.8	--	--	--	--	Khan and Marriage, 1977
4.4×10^{-2}	2.24	--	--	--	--	--	--	Sikka and Davis, 1966
5.0×10^{-2}	2.24	--	--	--	--	--	--	Ibid
5.0×10^{-2}	2.24	--	--	--	--	--	--	Ibid
5.8×10^{-2}	4.48	--	--	--	--	--	--	Ibid
5.8×10^{-2}	4.48	--	--	--	--	--	--	Ibid
3.7×10^{-2}	4.48	--	--	--	--	--	--	Ibid
4.4×10^{-2}	17.92	--	--	--	--	--	--	Ibid
5.7×10^{-2}	17.92	--	--	--	--	--	--	Ibid
5.3×10^{-2}	17.92	--	--	--	--	--	--	Ibid
2.2×10^{-2}	4.5	5.3	1.8	7.6	17.6(Ave.)	--	0-15	Marriage, et al., 1975

EPA-287 (Cin.)
(4-76)

Table B7. Solvent extractable simazine disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Depth (cm)	Reference
2.1×10^{-2}	4.5	5.3	1.8	7.6	17.6 (Ave.)	0-15	Marriage, et al., 1975
1.1×10^{-2}	2.8	7.9	5.1	16	--	0-23	Clay, 1973
1.1×10^{-2}	5.6	7.9	5.1	16	--	0-23	Ibid
2.8×10^{-2}	22.4	7.9	5.1	16	--	0-23	Ibid
6.2×10^{-2}	0.5	--	--	--	--	0-15.2	Joshi and Datta, 1975
5.9×10^{-2}	1.0	--	--	--	--	0-15.2	Ibid
5.5×10^{-2}	1.5	--	--	--	--	0-15.2	Ibid
7.6×10^{-3}	0.45	7.1	3.0	61.5	--	0-20	Roadhouse and Birk, 1961
1.1×10^{-2}	0.9	7.1	3.0	61.5	--	0-20	Ibid
1.5×10^{-2}	1.8	7.1	3.0	61.5	--	0-20	Ibid
1.3×10^{-2}	5.4	7.1	3.0	61.5	--	0-20	Ibid
1.1×10^{-2}	8.9	7.1	3.0	61.5	--	0-20	Ibid
1.0×10^{-2}	17.8	7.1	3.0	61.5	--	0-20	Ibid

Table B8. Solvent extractable atrazine disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
7.4×10^{-3}	0.67	7.3	2.0	20	--	--	Beynon, et al., 1972
8.9×10^{-3}	40	7.3	1.45	15	20	--	Hance, 1974
1.7×10^{-2}	10	6.3	(4)	--	30	60% FC	Obien and Green, 1969
2.4×10^{-2}	10	4.4	(10)	--	30	60% FC	Ibid
2.9×10^{-2}	10	5.9	(22)	--	30	60% FC	Ibid
2.9×10^{-2}	10	5.4	(29)	--	30	60% FC	Ibid
6.3×10^{-3}	8	--	--	--	13.2	40% FC	Zimdahl, et al., 1970
2.0×10^{-2}	8	--	--	--	31.2	40% FC	Ibid

Table B9. Solvent extractable simazine disappearance rates in soils under aerobic laboratory incubation.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
6.3×10^{-3}	0.67	7.3	2	20	--	--	Beynon, et al., 1972
1.9×10^{-2}	8	7	2	18	25	13.2	Walker, 1976a
1.5×10^{-2}	8	7	2	18	25	10.7	Ibid
1.3×10^{-2}	8	7	2	18	25	9.7	Ibid
1.1×10^{-2}	8	7	2	18	25	7.9	Ibid
9.0×10^{-3}	8	7	2	18	25	6.0	Ibid
8.2×10^{-3}	8	7	2	18	25	4.8	Ibid
6.2×10^{-3}	8	7	2	18	15	11.5	Ibid
3.0×10^{-3}	8	7	2	18	15	6.6	Ibid
1.8×10^{-2}	4	7	2	18	25	11.2	Ibid
3.3×10^{-3}	4	--	--	--	5	4	Walker, 1976b
5.0×10^{-3}	4	--	--	--	10	4	Ibid
7.5×10^{-3}	4	--	--	--	15	4	Ibid
1.2×10^{-2}	4	--	--	--	20	4	Ibid
1.7×10^{-2}	4	--	--	--	25	4	Ibid
2.4×10^{-2}	4	--	--	--	30	4	Ibid
2.5×10^{-2}	4	--	--	--	25	8	Ibid
5.5×10^{-3}	4	--	--	--	5	12	Ibid
8.7×10^{-3}	4	--	--	--	10	12	Ibid
1.3×10^{-2}	4	--	--	--	15	12	Ibid
2.0×10^{-2}	4	--	--	--	20	12	Ibid
7.0×10^{-3}	8	--	--	--	13.2	40% FC	Zimdahl, et al., 1970
1.8×10^{-2}	8	--	--	--	31.2	40% FC	Ibid

Table B10. Mineralization rates in soils from ring-labeled ^{14}C-atrazine under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Temp (°C)	Soil-water Content (%)	Reference
2.0×10^{-4}	10	4.7	10.5	24.5	67	Goswami and Green, 1971
6.7×10^{-6}	10	6.4	3.4	24.5	67	Ibid
4.6×10^{-5}	2.58	6.8	3.1	27	54.2	Skipper and Volk, 1972
9.2×10^{-5}	2.58	6.6	3.1	27	32.1	Ibid

Table B11. Solvent extractable trifluralin disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
4.4×10^{-3}	10	5.3	1.5	12.2	--	70% FC	Kearney, et al., 1976
7.5×10^{-3}	5	6.0	--	--	25	100% FC	Parr and Smith, 1973
8.1×10^{-3}	8	--	--	--	25	50% FC	Probst, et al., 1967
8.8×10^{-3}	8	--	--	--	25	100% FC	Ibid
1.8×10^{-3}	7.85	7.6	1.6	14	15	80% FC	Zimdahl and Gwynn, 1977
7.7×10^{-3}	7.85	7.6	1.6	14	30	80% FC	Ibid
2.5×10^{-3}	7.85	6.6	2.2	20	15	80% FC	Ibid
9.2×10^{-3}	7.85	6.6	2.2	20	30	80% FC	Ibid
1.3×10^{-2}	7.85	7.6	1.6	14	30	80% FC	Ibid
2.1×10^{-2}	7.85	6.6	2.2	20	30	80% FC	Ibid

Table B12. Solvent extractable trifluralin disappearance rates in soils incubated in the laboratory under anaerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	Temp (°C)	Soil-water Content (%)	Reference
9.9×10^{-3}	5	6.0	25	100% FC	Parr and Smith, 1973
2.0×10^{-2}	8	--	4	200% FC	Probst, et al., 1967
2.0×10^{-1}	8	--	25	200% FC	Ibid
6.9×10^{-2}	8	--	25	200% FC	Parr and Smith, 1973

Table B13. Solvent extractable trifluralin disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
1.9×10^{-2}	1.26	6.0	1.33	22.9	22(Ave)	--	0-30	Duseja and Holmes, 1978
2.7×10^{-2}	1.26	5.9	1.90	40.4	22(Ave)	--	0-30	Ibid
2.1×10^{-2}	1.1	8.1	0.8	16	--	13	0-2.5	Menge and Tamez, 1974
1.8×10^{-2}	1.1	8.1	0.8	16	--	13	0-7.5	Ibid
4.7×10^{-2}	4.48	--	--	--	--	--	0	Savage and Barrentine, 1969
1.7×10^{-2}	4.48	--	--	--	--	--	2.5-5	Ibid
1.1×10^{-2}	4.48	--	--	--	--	--	7.5-12	Ibid
1.4×10^{-2}	1.4	7.5	4.0	74	--	39.7	0-5	Smith, 1972
1.0×10^{-2}	1.4	6.1	8.8	39	--	35.6	0-5	Ibid

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

Table B14. Solvent extractable bromacil disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration ($\mu g/g$)	Temp (°C)	Soil-water Content (%)	Reference
1.2×10^{-2}	10			Gardiner, et al., 1969
4.5×10^{-3}	8	13.2	40% FC	Zimdahl, et al., 1970
6.3×10^{-3}	8	31.2	40% FC	Ibid

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table B15. Solvent extractable terbacil disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration ($\mu g/g$)	Temp (°C)	Soil-water Content (%)	Reference
1.2×10^{-2}	2.25			Gardiner, et al., 1969
1.2×10^{-2}	8	13.2	40% FC	Zimdahl, et al., 1970
2.0×10^{-2}	8	31.2	40% FC	Ibid

Table B16. Mineralization for bromacil in soils under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	Reference
4.6×10^{-3}	10	Gardiner, et al., 1969
4.2×10^{-4}	2.88	Wolf and Martin, 1974

Table B17. Mineralization rates for terbacil in soils under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	Reference
8.5×10^{-3}	2.25	Gardiner, et al., 1969
5.4×10^{-4}	2.88	Wolf and Martin, 1974

TYPING GUIDE SHEET

Table B18. Solvent extractable bromacil disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
$1.1x10^{-2}$	4.48				0-30.5	Gardiner, et al., 1969
$4.0x10^{-3}$	4.48				0-30.5	Ibid
$1.5x10^{-3}$	1.6	3.7	2.3	7.2	0-140	Leistru, et al., 1975
$8.7x10^{-4}$	2.4	3.7	2.3	7.2	0-140	Ibid
$3.9x10^{-3}$	1.6	5.5	3.1	36.9	0-140	Ibid
$1.6x10^{-3}$	2.4	5.5	3.1	36.9	0-140	Ibid

EPA-287 (Cin.)
(4-76)

Table B19. Solvent extractable terbacil disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
$9.2x10^{-3}$	4.48						0-30.5	Gardiner, et al., 1969
$5.3x10^{-3}$	4.48						0-30.5	Ibid
$1.7x10^{-3}$	4.5						0-5	Khan, 1977
$7.8x10^{-3}$	4.5						0-15	Ibid

Table B20. Solvent extractable linuron disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
$8.0x10^{-3}$	4	7.3	1.45	15	20	16.7	Hance, 1974
$8.9x10^{-3}$	10	7.3	2.5	15	20	20	Moyer, et al., 1972
$2.4x10^{-3}$	10	6.9	4.3	27.2	4	0.25 WHC(FC)	Usorol and Hance, 1974
$2.5x10^{-3}$	10	6.9	4.3	27.2	4	0.5 WHC(FC)	Ibid
$3.7x10^{-3}$	10	6.9	4.3	27.2	4	1 WHC(FC)	Ibid
$7.9x10^{-3}$	10	6.9	4.3	27.2	22	0.25 WHC(FC)	Ibid
$1.1x10^{-2}$	10	6.9	4.3	27.2	22	0.5 WHC(FC)	Ibid
$1.2x10^{-2}$	10	6.9	4.3	27.2	22	1 WHC(FC)	Ibid

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table B21. Solvent extractable linuron disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
2.8×10^{-3}	2.2	7.3	4	69	--	--	0-5	Smith and Edmond, 1975
5.2×10^{-3}	2.2	6.7	3	6	--	--	0-5	Ibid
2.0×10^{-3}	2.2	5.6	3	9	--	--	0-5	Ibid
3.5×10^{-3}	2.2	5.6	3	9	--	--	0-5	Ibid

Table B22. Solvent extractable diuron disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	OM (%)	Clay (%)	Temp (°C)	Depth (cm)	Reference
$5.0x10^{-3}$	1.12	--	--	--	0-10	Hill, et al., 1955
$4.2x10^{-3}$	1.12	--	--	--	0-10	Ibid
$5.2x10^{-3}$	1.12	--	--	--	0-10	Ibid
$3.3x10^{-3}$	2.24	--	--	--	0-10	Ibid
$5.0x10^{-3}$	2.24	--	--	--	0-10	Ibid
$1.3x10^{-3}$	4.5	1.1	5.1	9	0-15	Khan, et al., 1976
$1.3x10^{-3}$	4.5	1.1	5.1	9	0-15	Ibid

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA

Table B23. Solvent extractable dicamba disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
2.2×10^{-2}	2.47	--	3.3	15.5	22	--	Altom and Stritzke, 1973
2.2×10^{-2}	2.47	--	2.8	16.5	22	--	Ibid
4.1×10^{-2}	2.47	--	3.8	18.5	22	--	Ibid
2.0×10^{-2}	2	7.5	3.2	6	25	5	Smith, 1973
2.1×10^{-1}	2	7.5	3.2	6	25	10	Ibid
2.1×10^{-1}	2	5.2	11.7	30	25	20	Ibid
5.3×10^{-2}	2	7.7	4.2	69	25	25	Ibid
7.3×10^{-2}	2	7.7	4.2	69	25	30	Ibid
9.0×10^{-2}	2	7.7	4.2	69	25	35	Ibid
$\sim\propto$	2	5.2	11.7	30	25	28	Ibid
$\sim\propto$	2	5.2	11.7	30	25	35	Ibid
3.0×10^{-2}	3.5	7.7	4.2	69	25	40% FC	Smith, 1974
2.4×10^{-2}	2.8	7.7	4.2	69	25	40% FC	Ibid
1.3×10^{-2}	2	5.2	11.7	30	6	36% FC	Smith and Cullimore, 1975
6.0×10^{-2}	2	5.2	11.7	30	10	36% FC	Ibid
1.5×10^{-1}	2	5.2	11.7	30	15	36% FC	Ibid
1.5×10^{-1}	2	5.2	11.7	30	20	36% FC	Ibid
2.5×10^{-1}	2	5.2	11.7	30	30	36% FC	Ibid
2.5×10^{-1}	2	5.2	11.7	30	40	36% FC	Ibid

(Continued)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table B23. (Continued)

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
~0	2	7.5	3.2	6	6	11% FC	Smith and Cullimore, 1975
1.8×10^{-2}	2	7.5	3.2	6	10	11% FC	Ibid
6.5×10^{-2}	2	7.5	3.2	6	15	11% FC	Ibid
9.6×10^{-2}	2	7.5	3.2	6	20	11% FC	Ibid
2.5×10^{-2}	2	7.5	3.2	6	30	11% FC	Ibid
1.6×10^{-2}	2	7.5	3.2	6	40	11% FC	Ibid
9.5×10^{-3}	2	7.7	4.2	69	6	40% FC	Ibid
2.8×10^{-2}	2	7.7	4.2	69	10	40% FC	Ibid
3.8×10^{-2}	2	7.7	4.2	69	15	40% FC	Ibid
7.3×10^{-2}	2	7.7	4.2	69	20	40% FC	Ibid
1.9×10^{-1}	2	7.7	4.2	69	30	40% FC	Ibid
1.9×10^{-1}	2	7.7	4.2	69	40	40% FC	Ibid

Table B24. Solvent extractable dicamba disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Depth (cm)	Reference
$1.1\text{x}10^{-1}$	0.28	6.94	0.81	17	--	0-15	Scifres and Allen, 1973
$1.0\text{x}10^{-1}$	0.56	6.94	0.81	17	--	0-15	Ibid
$9.5\text{x}10^{-2}$	0.28	6.45	2.35	45	--	0-15	Ibid
$1.0\text{x}10^{-1}$	0.56	6.45	2.35	45	--	0-15	Ibid
$7.7\text{x}10^{-2}$	1.1	5.8	2.6	25	5.3	0-10	Stewart and Gaul, 1977
$7.2\text{x}10^{-2}$	2.2	5.8	2.6	25	5.3	0-10	Ibid

TYPING GUIDE SHEET

Table B25. Solvent extractable picloram disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
3.1×10^{-3}	4	6.8	2.7	48	19.5	23	Meikle, et al., 1973
3.7×10^{-3}	4	7.5	0.3	16	19.5	6	Ibid
5.4×10^{-3}	4	7.2	4.1	7	19.5	30	Ibid
6.7×10^{-3}	4	7.8	3.1	25	19.5	25	Ibid
5.6×10^{-4}	4	6.3	1.2	42	19.5	16	Ibid
5.2×10^{-3}	4	6.2	3.2	28	19.5	30	Ibid
3.8×10^{-4}	4	5.9	0.3	16	19.5	12	Ibid
2.6×10^{-3}	4	5.7	1.5	6	19.5	17	Ibid
5.2×10^{-3}	4	6.2	3.2	28	19.5	58	Ibid
3.6×10^{-3}	4	6.2	3.2	28	19.5	45	Ibid
3.3×10^{-3}	4	6.2	3.2	28	19.5	32	Ibid
2.6×10^{-3}	4	6.2	3.2	28	19.5	11	Ibid
1.9×10^{-3}	4	6.2	3.2	28	19.5	5	Ibid
4.8×10^{-3}	4	6.2	3.2	28	34	30	Ibid
2.8×10^{-3}	4	6.2	3.2	28	19.5	30	Ibid
1.8×10^{-3}	4	6.2	3.2	28	2.5	30	Ibid
7.9×10^{-3}	4	5.7	1.0	7	34	8	Ibid
2.6×10^{-3}	4	5.7	1.0	7	19.5	8	Ibid
2.0×10^{-3}	4	5.7	1.0	7	2.5	8	Ibid

(Continued)

EPA-287 (Cin.)
(4-76)

Table B25. (Continued).

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
8.2×10^{-3}	0.25	--	--	--	4	100% FC	Merkle, et al., 1976
8.2×10^{-3}	0.25	--	--	--	4	10% FC	Ibid
6.4×10^{-3}	0.25	--	--	--	20	100% FC	Ibid
6.4×10^{-3}	0.25	--	--	--	20	10% FC	Ibid
2.4×10^{-2}	0.25	--	--	--	38	100% FC	Ibid
1.3×10^{-2}	0.25	--	--	--	38	10% FC	Ibid
1.0×10^{-2}	0.25	--	--	--	4	100% FC	Ibid
1.0×10^{-2}	0.25	--	--	--	20	100% FC	Ibid
5.0×10^{-3}	0.25	--	--	--	20	10% FC	Ibid
1.0×10^{-2}	0.25	--	--	--	38	100% FC	Ibid
6.4×10^{-3}	0.25	--	--	--	38	10% FC	Ibid
9.6×10^{-3}	1.0	--	--	--	4	100% FC	Ibid
1.5×10^{-2}	1.0	--	--	--	4	10% FC	Ibid
8.6×10^{-3}	1.0	--	--	--	20	100% FC	Ibid
8.9×10^{-3}	1.0	--	--	--	20	10% FC	Ibid
9.1×10^{-3}	1.0	--	--	--	38	100% FC	Ibid
9.1×10^{-3}	1.0	--	--	--	38	10% FC	Ibid
1.4×10^{-2}	1.0	--	--	--	4	100% FC	Ibid
8.6×10^{-3}	1.0	--	--	--	4	10% FC	Ibid
1.1×10^{-2}	1.0	--	--	--	20	100% FC	Ibid
9.4×10^{-3}	1.0	--	--	--	20	10% FC	Ibid
1.0×10^{-2}	1.0	--	--	--	38	100% FC	Ibid
9.9×10^{-3}	1.0	--	--	--	38	10% FC	Ibid
5.5×10^{-3}	1	6.6	2.0	--	30	--	Yoshida and Castro, 1975
3.0×10^{-3}	1	4.7	3.2	--	30	--	Ibid

EPA-287 (Cin.)
(4-76)

Table B26. Mineralization rates for carboxy-^{14}C-labeled picloram in soils under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
5.0×10^{-6}	10	7.9	0.90	24.5	5	100% FC	Guenzi and Beard, 1976
2.5×10^{-5}	10	7.9	0.90	24.5	15	100% FC	Ibid
5.0×10^{-5}	10	7.9	0.90	24.5	25	100% FC	Ibid
2.9×10^{-4}	10	7.9	0.90	24.5	30	100% FC	Ibid
1.1×10^{-4}	10	7.9	0.90	24.5	50	100% FC	Ibid
2.0×10^{-5}	10	7.9	0.83	39.0	5	100% FC	Ibid
1.0×10^{-4}	10	7.9	0.83	39.0	15	100% FC	Ibid
3.7×10^{-4}	10	7.9	0.83	39.0	25	100% FC	Ibid
1.0×10^{-3}	10	7.9	0.83	39.0	30	100% FC	Ibid
5.2×10^{-4}	10	7.9	0.83	39.0	50	100% FC	Ibid
2.5×10^{-5}	10	5.5	4.20	27.0	5	100% FC	Ibid
1.5×10^{-4}	10	5.5	4.20	27.0	15	100% FC	Ibid
5.5×10^{-4}	10	5.5	4.20	27.0	25	100% FC	Ibid
1.2×10^{-3}	10	5.5	4.20	27.0	30	100% FC	Ibid
1.7×10^{-4}	10	5.5	4.20	27.0	50	100% FC	Ibid
~ 0	10	6.8	3.41	83.0	5	100% FC	Ibid
1.0×10^{-5}	10	6.8	3.41	83.0	15	100% FC	Ibid
4.0×10^{-5}	10	6.8	3.41	83.0	25	100% FC	Ibid
2.1×10^{-4}	10	6.8	3.41	83.0	30	100% FC	Ibid
3.1×10^{-4}	10	6.8	3.41	83.0	50	100% FC	Ibid
1.5×10^{-5}	10	7.1	1.37	8.0	5	100% FC	Ibid
1.1×10^{-4}	10	7.1	1.37	8.0	15	100% FC	Ibid
1.8×10^{-4}	10	7.1	1.37	8.0	25	100% FC	Ibid
1.2×10^{-3}	10	7.1	1.37	8.0	30	100% FC	Ibid
1.7×10^{-3}	10	7.1	1.37	8.0	50	100% FC	Ibid

(Continued)

TYPING GUIDE SHEET
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table B26. (Continued).

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
2.2×10^{-4}	4	7.0	1.1	9	27	7.6	Meikle, et al., 1966
2.8×10^{-3}	4	7.0	1.1	9	27	7.6	Ibid
7.8×10^{-4}	3.20	6.8	2.7	48	19.5	23	Meikle, et al., 1973
1.3×10^{-3}	1.60	6.8	2.7	48	19.5	23	Ibid
1.5×10^{-3}	0.80	6.8	2.7	48	19.5	23	Ibid
1.9×10^{-3}	0.40	6.8	2.7	48	19.5	23	Ibid
2.2×10^{-3}	0.20	6.8	2.7	48	19.5	23	Ibid
2.5×10^{-3}	0.10	6.8	2.7	48	19.5	23	Ibid
2.6×10^{-3}	0.05	6.8	2.7	48	19.5	23	Ibid
3.7×10^{-4}	4	6.2	3.2	28	19.5	58	Ibid
6.1×10^{-4}	4	6.2	3.2	28	19.5	45	Ibid
5.8×10^{-4}	4	6.2	3.2	28	19.5	32	Ibid
4.1×10^{-4}	4	6.2	3.2	28	19.5	11	Ibid
2.0×10^{-4}	4	6.2	3.2	28	19.5	5	Ibid
1.3×10^{-3}	4	6.2	3.2	28	34	30	Ibid
8.7×10^{-4}	4	6.2	3.2	28	19.5	30	Ibid
1.1×10^{-4}	4	6.2	3.2	28	2.5	30	Ibid
4.0×10^{-3}	4	5.7	1.5	6	34	8	Ibid
9.0×10^{-4}	4	5.7	1.5	6	19.5	8	Ibid
1.1×10^{-4}	4	5.7	1.5	6	2.5	8	Ibid

Table B27. Solvent extractable picloram disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Depth (cm)	Reference
$1.8x10^{-2}$	1.12	--	--	--	--	--	0-15	Bovey, et al., 1969
$1.3x10^{-2}$	3.36	--	--	--	--	--	0-15	Ibid
$3.4x10^{-2}$	10.08	--	--	--	--	--	0-15	Ibid
$>4.3x10^{-2}$	1.12	--	--	--	--	--	0-15	Ibid
$>5.7x10^{-2}$	3.36	--	--	--	--	--	0-15	Ibid
$5.1x10^{-2}$	10.08	--	--	--	--	--	0-15	Ibid
$3.4x10^{-2}$	2.24	6.4	1.72	--	22(mean)	--	0-15	Lutz, et al., 1973
$3.6x10^{-2}$	4.48	6.4	1.72	--	22(mean)	--	0-15	Ibid
$8.3x10^{-3}$	--	--	--	--	--	--	0-15	Sirons, et al., 1977

Table B28. Solvent extractable dalapon disappearance rates in soils under laboratory aerobic incubation.

k_1 (day^{-1})	Concentration (μg/g)	Soil-water Content (%)	Reference
4.2×10^{-2}	50	100% FC	Namdeo, 1972
5.1×10^{-2}	10	100% FC	Ibid

Table B29. Solvent extractable TCA disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
9.6×10^{-2}	20				25	100% FC	McGrath, 1976
6.2×10^{-2}	10	7.5	3.2	6	25	10	Smith, 1974
1.2×10^{-1}	10	5.2	11.7	30	25	35	Ibid
8.9×10^{-3}	10	5.2	11.7	30	25	20	Ibid
2.3×10^{-2}	10	7.7	4.2	69	25	40	Ibid
4.8×10^{-3}	10	7.7	4.2	69	25	20	Ibid

Table B30. Solvent extractable TCA disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
$5.5x10^{-2}$	22.4	6.1	1.82	13	0-15	McGrath, 1976
$3.7x10^{-2}$	22.4	6.1	1.82	13	0-15	Ibid

Table B31. Solvent extractable glyphosate disappearance rates in soil under greenhouse conditions.

k_1 (day-1)	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
$2.6x10^{-2}$	4	7.0	6.0	36.8	26-32	11	Rueppel, et al., 1977
$2.8x10^{-2}$	8	7.0	6.0	36.8	26-32	11	Ibid
$5.3x10^{-3}$		5.7	1.0	2.3	26-32	11	Ibid
$2.3x10^{-1}$	4	6.5	1.0	0.6	26-32	11	Ibid
$2.3x10^{-1}$	8	6.5	1.0	0.6	26-32	11	Ibid

Table B32. Mineralization rates for glyphosate in soils incubated in the laboratory under aerobic incubation.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Temp (°C)	Reference
$1.6x10^{-2}$		6.6	3.8	25	Moshier and Penner, 1978
$3.3x10^{-3}$		5.6	3.7	25	Ibid
$1.1x10^{-3}$		4.4	1.2	25	Ibid
$1.8x10^{-2}$	375	6.9	2.10		Normura and Hilton, 1977
$1.4x10^{-2}$	366	7.0	3.07		Ibid
$7.3x10^{-3}$	365	6.1	4.88		Ibid
$2.0x10^{-4}$	376	5.7	9.48		Ibid
$1.3x10^{-4}$	373	5.5	9.71		Ibid
$2.3x10^{-2}$	2.7	2.7	5.7		Sprankle, et al., 1975
$6.2x10^{-3}$	2.7	--	--		Ibid
$5.0x10^{-3}$	2.7	3.8	3.8		Ibid

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Table B33. Solvent extractable parathion disappearance rate in soils under laboratory aerobic incubation.

k_1 (day-1)	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Reference
$1.4x10^{-2}$	1	7.2	1.3	0	27	Katan, et al., 1976
$5.0x10^{-3}$	1	6.0	4.7	24	27	Ibid
$3.3x10^{-2}$	200	--	--	--	30	Lichtenstein and Schulz, 1964
$3.3x10^{-2}$	6	--	--	--	26	Sacher, et al., 1971

Table B34. Solvent extractable parathion disappearance rates in the flooded soils incubated in the laboratory.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Temp (°C)	Reference
2.0×10^{-1}	30	6.0	1.35	30	Rajarium and Sethunathan, 1975
7.9×10^{-2}	50	3.15	12.20	30	Sethunathan, 1973a
6.1×10^{-2}	50	3.15	5.90	30	Ibid
6.1×10^{-2}	50	3.50	3.20	30	Ibid
3.2×10^{-2}	50	5.25	0.95	30	Ibid
3.6×10^{-2}	50	5.50	0.80	30	Ibid
3.7×10^{-2}	50	--	--	30	Sethunathan, 1973c
4.3×10^{-1}	150	6.6	2.0	30	Sethunathan and Yoshida, 1973
1.1×10^{-1}	150	4.7	3.2	30	Ibid
7.7×10^{-2}	150	7.6	1.5	30	Ibid
5.6×10^{-2}	150	4.8	4.4	30	Ibid

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Table B35. Solvent extractable parathion disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	Temp (°C)	Depth (cm)	Reference
2.8×10^{-2}	5.6	30	0-12	Lichtenstein and Schulz, 1964
3.0×10^{-2}	1.1			Sacher, et al., 1971
3.0×10^{-2}	1.1			Ibid
3.2×10^{-2}	1.1			Ibid
5.7×10^{-2}	1.1			Ibid
3.8×10^{-2}	1.1			Ibid
2.8×10^{-2}	1.1			Ibid
2.3×10^{-1}	2.24			Spencer, et al., 1975
1.0×10^{-1}	4.48			Ibid
5.2×10^{-2}	8.96			Ibid
2.4×10^{-2}	--			Ibid
3.5×10^{-2}	--			Ibid

Table B36. Solvent extractable methylparathion disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
9.5×10^{-2}	10	6.0	4.2	2.3	27	20	Lichtenstein, et al., 1977
2.3×10^{-1}	200	--	--	--	30	--	Lichtensetin and Schulz, 1964

Table B37. Solvent extractable diazinon disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
$1.8x10^{-2}$	0.45	6.0	2.0	2.6	30	75% WHC	Bro-Rasmussen, et al., 1968
$1.3x10^{-2}$	0.45	6.0	2.0	2.6	30	25% WHC	Ibid
$1.2x10^{-2}$	4.5	6.0	2.0	2.6	30	75% WHC	Ibid
$1.2x10^{-2}$	4.5	6.0	2.0	2.6	30	25% WHC	Ibid
$3.2x10^{-2}$	0.45	6.3	2.7	8.6	30	75% WHC	Ibid
$1.6x10^{-2}$	0.45	6.3	2.7	8.6	30	25% WHC	Ibid
$2.6x10^{-2}$	4.5	6.3	2.7	8.6	30	75% WHC	Ibid
$1.4x10^{-2}$	4.5	6.3	2.7	8.6	30	25% WHC	Ibid
$1.0x10^{-1}$	16.7	6.7	3.1	21	25	21	Getzin, 1967
$5.6x10^{-3}$	16.7	6.7	3.1	21	15	20	Getzin, 1968
$1.2x10^{-2}$	16.7	6.7	3.1	21	25	20	Ibid
$2.2x10^{-2}$	16.7	6.7	3.1	21	35	20	Ibid

Table B38. Solvent extractable diazinon disappearance rates in flooded soils incubated in the laboratory.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Reference
7.2×10^{-2}	4.9	6.2	5.4	--	25	Laanio, et al., 1972
7.9×10^{-2}	50	6.6	2.0	--	30	Sethunathan and MacRae, 1969
4.0×10^{-2}	50	7.6	1.5	--	30	Ibid
2.0×10^{-1}	50	4.7	3.2	--	30	Ibid
9.1×10^{-2}	40	6.6	2.0	--	--	Sethunathan and Yoshida, 1969

Table B39. Solvent extractable fonofos disappearance rates in the field (complex first-order).

k_1' (day-1)	k_1'' (day-1)	Concentration (kg/ha)	pH	Temp (°C)	Depth (cm)	Reference
$3.6x10^{-2}$	$5.3x10^{-3}$	5.35	5.7	19	0-15	Kiigemgi and Terriere, 1971
$2.4x10^{-2}$	$9.5x10^{-3}$	11.2	--	--	0-15	Schulz and Lichtenstein, 1971

Table B40. Solvent extractable fonofos disappearance rates in the field (simple first-order).

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
7.4×10^{-3}	2.24	5.7	43.4	--	0-10	Mathur, et al., 1976
2.7×10^{-2}	10	8.5	0.54	16.3	0-15	Talekar, et al., 1977

Table B41. Solvent extractable malathion disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
9.2×10^{-1}	20	5.4	6.8	20	25	65% WHC	Gibson and Burns, 1977
2.48	5	6.4	--	--	--	--	Konrad, et al., 1969
3.11	5	7.2	48.7	--	--	--	Ibid
1.66	5	3.8	--	--	--	--	Ibid
<0.69	16	7.2	2.75	--	25-26	28.3	Walker and Stojanovic, 1973
0.33	16	5.3	0.62	--	25-26	13.1	Ibid
<0.69	16	7.4	1.82	--	25-26	28	Ibid

Table B42. Solvent extractable phorate disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
7.6×10^{-2}	4	--	--	--	24	--	Getzin and Chapman, 1960
9.0×10^{-2}	4	--	--	--	24	--	Ibid
1.0×10^{-1}	4	--	--	--	24	--	Ibid
8.4×10^{-3}	17	6.3	3.1	21	25		Getzin and Shank, 1970

Table B44. Solvent extractable carbofuran disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
9.5×10^{-2}	8.3	7.8	1.0	19	25	1.05 FC	Getzin, 1973
1.1×10^{-1}	13.9	7.8	1.0	19	25	1.05 FC	Ibid
5.3×10^{-2}	10.0	6.2	7.2	36	25	1.05 FC	Ibid
4.3×10^{-2}	16.7	6.2	7.2	36	25	1.05 FC	Ibid
1.4×10^{-2}	8.3	6.0	3.0	17	25	1.05 FC	Ibid
9.4×10^{-3}	16.7	5.9	40.0	--	25	1.05 FC	Ibid
7.5×10^{-3}	50	6.2	1.61	--	--	0.5 FC	Venkateswarlu, et al., 1977

Table B43. Solvent extractable phorate disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	Depth (cm)	Reference
7.9×10^{-3}	2.24	0-10	Menzer, et al., 1970
1.4×10^{-2}	2.24	0-10	Ibid
9.2×10^{-3}	2.24	0-10	Ibid
8.0×10^{-3}	4.48	0-10	Ibid
8.1×10^{-2}	2	0-15	Suett, 1975
9.5×10^{-2}	2	0-15	Ibid

Table B45. Solvent extractable carbofuran disappearance rates in flooded soils.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Soil-water Content (%)	Reference
$4.0x10^{-2}$	50	6.2	1.61	125	Venkateswarlu, et al., 1977
$2.9x10^{-2}$	50	5.0	3.25	125	Ibid
$2.6x10^{-2}$	50	4.2	8.21	125	Ibid
$6.5x10^{-3}$	50	3.0	26.41	125	Ibid

Table B46. Solvent extractable carbofuran disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Temp (°C)	Depth (cm)	Reference
1.50×10^{-2}	5.41	5.20 & 6.35	--	--	--	0-10	Caro, et al., 1973
5.9×10^{-3}	5.41	5.20 & 6.35	--	--	--	0-10	Ibid
7.4×10^{-3}	4.16	5.20 & 6.35	--	--	--	0-15	Ibid
4.1×10^{-2}	4.48	5.7	43.4	--	--	0-10	Mathur, et al., 1976
2.2×10^{-2}	4.48	5.7	43.4	--	--	0-10	Ibid
6.9×10^{-2}	10	8.5	0.54	16.3	~28	0-15	Talekar, et al., 1977

Table B47. Mineralization rates of ^{14}C-labeled carbofuran in soils under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
			Ring Labeled				
1.6×10^{-3}	13.9	7.8	1.0	19	25	105% FC	Getzin, 1973
1.1×10^{-3}	16.7	6.2	7.2	36	25	105% FC	Ibid
			Carbonyl Labeled				
5.6×10^{-2}	8.3	7.8	1.0	19	25	105% FC	Getzin, 1973
5.9×10^{-2}	10.0	6.2	7.2	36	25	105% FC	Ibid
1.2×10^{-2}	8.3	6.0	3.0	17	25	105% FC	Ibid
6.1×10^{-3}	16.7	5.9	40.0	--	25	105% FC	Ibid

Table B48. Solvent extractable carbaryl disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Soil-water Content (%)	Reference
				Ring labeled			
2.5×10^{-2}	2	5.4	5.8	40	25	80% FC	Kazano, et al., 1972
3.4×10^{-2}	2	6.1	12.8	21	25	80% FC	Ibid
7.3×10^{-2}	2	6.3	1.5	19	25	80% FC	Ibid
2.1×10^{-2}	2	5.6	4.1	28	25	80% FC	Ibid
3.3×10^{-2}	2	5.5	3.3	11	25	80% FC	Ibid

Table B49. Solvent extractable carbaryl disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
2.8×10^{-2}	5.03	5.20	1.7	16	0-30	Caro, et al., 1974
8.7×10^{-2}	3.436-30.24	--	--	--	0-15	Johnson and Stansbury, 1975
$>1.9 \times 10^{-1}$	3.36	--	--	--	0-5	Kuhr, et al., 1974

Table B50. Solvent extractable DDT disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
3.1×10^{-4}	11.2	--	--	--	0-15	Lichtenstein, et al., 1971
2.6×10^{-4}	112.0	--	--	--	0-15	Ibid
1.1×10^{-3}	112	6.9	1.8	--	0-15	Lichtenstein, et al., 1960
1.6×10^{-3}	112	6.8	0.8	--	0-15	Ibid
8.1×10^{-4}	112	4.9	74.5	--	0-15	Ibid
6.9×10^{-4}	112	6.0	2.0	--	0-15	Ibid
4.7×10^{-4}	112	7.2	0.8	--	0-15	Ibid
4.2×10^{-4}	112	7.1	3.6	--	0-15	Ibid
7.7×10^{-4}	112	6.8	40.0	--	0-15	Ibid
1.2×10^{-3}(first 1/2 yr)	11.2	--	40.0	--	0-15	Lichtenstein and Schulz, 1959b
8.4×10^{-4}(3 years)	11.2	--	40.0	--	0-15	Ibid
3.0×10^{-3}(first 1/2 yr)	11.2	--	3.8	--	0-15	Ibid
9.4×10^{-4}(3 years)	11.2	--	3.8	--	0-15	Ibid
4.4×10^{-4}	28	4.7	--		0-15	Nash and Woolson, 1967
2.7×10^{-4}	112	4.7	--		0-15	Ibid
1.5×10^{-4}	448	4.7	--		0-15	Ibid
2.7×10^{-4}	112	--	--		0-15	Ibid
1.2×10^{-4}	448	--	--		0-15	Ibid
1.7×10^{-4}	112	5.2	--		0-15	Ibid
1.2×10^{-4}	448	5.2	--		0-15	Ibid
$<4.0\times10^{-4}$	587	--	--		0-30	Stewart and Chisholm, 1971
9.2×10^{-4}	--	--	--		--	Suzuki, et al., 1977

(Continued)

Table B50. (Continued)

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
1.0×10^{-3}(aerobic)	56	8.4	1.9		0-15	Guenzi, et al., 1971
3.9×10^{-3}(flooded)	56	8.4	1.9		0-15	Ibid
2.6×10^{-3}	5	8.5	0.54	16.3	0-15	Talekar, et al., 1977
6.5×10^{-3}	2.24				0-1.27	Ware, et al., 1977
5.1×10^{-3}	2.24				0-1.27	Ibid
4.2×10^{-3}	2.24				0-1.27	Ibid
3.9×10^{-3}	2.24				0-1.25	Ibid
7.1×10^{-5}	--	--	3.0		0-60	Voerman and Besemer, 1975

Table B51. Solvent extractable DDT disappearance rates in flooded or anaerobic soils incubated in the laboratory.

k_1 (day-1)	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Reference
1.6×10^{-3}	10-20	5.9	4.64	34	28	Burge, 1971
8.7×10^{-3}	10-20	5.9	4.64	34	28	Ibid
7.1×10^{-3}	200	6.2	4.64	34.3	35	Glass, 1972
3.4×10^{-3}	200	7.5	2.68	52.6	35	Ibid
3.6×10^{-4}	200	5.0	1.72	15.6	35	Ibid
3.6×10^{-4}	200	5.4	0.1	13.8	35	Ibid
4.5×10^{-3}	10	6.4	3.1	29.8	30	Guenzi and Beard, 1976
7.3×10^{-3}	10	6.4	3.1	29.8	40	Ibid
5.8×10^{-3}	10	6.4	3.1	29.8	50	Ibid
1.5×10^{-2}	10	6.4	3.1	29.8	60	Ibid

Table B52. Solvent extractable aldrin and dieldrin disappearance rates in the field.

k_1 (day-1)	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
4.9×10^{-4}	44.8	7.8	1.04	49.3	0-15	Cliath and Spencer, 1971
2.1×10^{-4}	44.8	7.8	0.48	17.5	0-15	Ibid
1.3×10^{-3}	56	8.4	1.9		0-15	Guenzi, et al., 1971
1.5×10^{-3}	56	8.4	1.9		0-15	Ibid
3.0×10^{-3}	22.4				0-15	Lichtenstein and Schulz, 1959a
2.3×10^{-3}	224				0-15	Ibid
4.1×10^{-3}	22.4				0-15	Ibid
2.0×10^{-3}	224				0-15	Ibid
6.2×10^{-3}	22.4	--	40.0	--	0-15	Lichtenstein and Schulz, 1959a
1.8×10^{-3}	22.4	--	40.0	--	0-15	Ibid
9.6×10^{-3}	22.4	--	3.8	--	0-15	Ibid
2.4×10^{-3}	22.4	--	3.8	--	0-15	Ibid
9.8×10^{-4}	28				0-12.7	Lichtenstein, et al., 1970
7.9×10^{-4}	28				0-12.7	Ibid
7.0×10^{-5}					0-60	Voerman and Besemer, 1975
1.9×10^{-3}	5.6				0-15	Wilkinson and Finlayson, 1964
1.8×10^{-3}	5.6				0-15	Ibid
1.3×10^{-4}	22.4	6.2	0.83		0-15	Willis, et al., 1972
4.8×10^{-4}	22.4	6.2	0.83		0-15	Ibid
1.3×10^{-3}	22.4	6.2	0.83		0-15	Ibid

Table B53. Solvent extractable aldrin and dieldrin disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Clay (%)	Temp (°C)	Reference
1.8×10^{-3}	10	6.0	4.2	23	27	Lichtenstein, et al., 1977
3.3×10^{-3}	20	--	3.8	--	7	Lichtenstein and Schulz, 1959b
1.0×10^{-2}	20	--	3.8	--	26	Ibid
3.8×10^{-2}	20	--	3.8	--	46	Ibid

Table B54. Solvent extractable endrin disappearance rates in the field.

k_1 (day-1)	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Reference
$1.5x10^{-3}$	56	8.4	1.9		Guenzi, et al., 1971
$5.3x10^{-3}$	56	8.4	1.9		Ibid

Table B55. Solvent extractable endrin disappearance rate in flooded soils under laboratory incubation conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Reference
$4.0x10^{-2}$	25	6.2	1.61	Gowa and Sethunathan, 1976
$5.2x10^{-2}$	25	4.8	2.38	Ibid
$5.5x10^{-2}$	25	5.0	3.25	Ibid
$2.0x10^{-2}$	25	5.0	1.24	Ibid
$1.9x10^{-2}$	25	5.9	1.89	Ibid
$5.0x10^{-2}$	25	4.2	9.21	Ibid
$2.1x10^{-2}$	25	3.0	27.81	Ibid
$8.8x10^{-2}$	25	6.0	0.02	Ibid
$1.8x10^{-2}$	25	6.2	1.61	Gowa and Sethunathan, 1977
$1.7x10^{-2}$	25	5.0	3.25	Ibid
$2.9x10^{-2}$	25	4.2	8.21	Ibid

Table B56. Solvent extractable chlordane disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
$8.0x10^{-3}$	3.4					Harris and Suns, 1975
$6.9x10^{-5}$	3.4					Ibid
$2.7x10^{-3}$	3.4					Ibid
$6.6x10^{-4}$	3.4					Ibid
$7.9x10^{-3}$	3.4					Ibid
$9.0x10^{-4}$	3.4					Ibid
$2.8x10^{-3}$	3.4					Ibid
$2.7x10^{-4}$	3.4					Ibid
$<4.6x10^{-4}$	336	--	--	--	0-60	Stewart and Chisholm, 1971
$3.7x10^{-3}$	3	7.9	1.7	28.6	0-30	Tafuri, et al., 1977
$3.0x10^{-3}$	6	7.9	1.7	28.6	0-30	Ibid
$2.2x10^{-3}$	3	7.9	1.7	28.6	0-30	Ibid
$2.5x10^{-3}$	5.6	6.9	1.5	4	0-23	Wilson and Oloffs, 1973
$1.8x10^{-3}$	5.6	6.9	1.5	4	0-23	Ibid
$1.4x10^{-3}$	11.2	4.3	9.8	35	0-23	Ibid
$7.9x10^{-4}$	11.2	4.3	9.8	35	0-23	Ibid

Table B57. Solvent extractable heptachlor disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Depth (cm)	Reference
5.4×10^{-3}	56	8.4	1.9	0-15	Guenzi, et al., 1971
1.4×10^{-2}	56	8.4	1.9		Ibid
1.1×10^{-3}	5.6			0-12.7	Lichtenstein, et al., 1970
7.8×10^{-4}	5.6				Ibid
1.7×10^{-3}	5.6			0-15	Wilkinson and Finlayson, 1964

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

Table B58. Solvent extractable heptachlor disappearance rates in soils under laboratory aerobic incubation.

k_1 (day^{-1})	Concentration (μg/g)	OM (%)	Temp (°C)	Reference
5.6×10^{-3}	20	3.8	7	Lichtenstein and Schulz, 1959b
1.2×10^{-2}	20	3.8	26	Ibid
7.2×10^{-2}	20	3.8	46	Ibid

Table B59. Solvent extractable lindane disappearance rates in the field.

k_1 (day^{-1})	Concentration (kg/ha)	pH	OM (%)	Clay (%)	Depth (cm)	Reference
2.3×10^{-3}	44.8	7.8	1.04	49.3	0-15	Cliath and Spencer, 1971
2.9×10^{-3}	44.8	7.8	0.48	17.5	0-15	Ibid
4.1×10^{-3}	56	8.4	1.9	--	0-15	Guenzi, et al., 1971
7.9×10^{-3}	56	8.4	1.9		0-15	Ibid
2.0×10^{-3}	11.2				0-15	Lichtenstein and Schulz, 1959a
1.4×10^{-3}	112				0-15	Ibid
1.7×10^{-3}	11.2				0-15	Ibid
1.3×10^{-3}	112				0-15	Ibid
1.5×10^{-3}	11.2	--	40		0-15	Lichtenstein and Schulz, 1959b
8.2×10^{-4}	11.2	--	40		0-15	Ibid
4.9×10^{-3}	11.2	--	3.8		0-15	Ibid
2.0×10^{-3}	11.2	--	3.8		0-15	Ibid
1.1×10^{-3}	11.2				0-15	Lichtenstein, et al., 1971
1.2×10^{-3}	112.0				0-15	Ibid
6.0×10^{-4}			3.0		0-60	Voerman and Besemer, 1975

Table B60. Solvent extractable lindane disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Soil-water Content (%)	Reference
3.1×10^{-3}	32.7	5.8	5.2	67% FC	Mathur and Saha, 1977
2.1×10^{-3}	32.7	5.8	5.2	67% FC	Ibid

Table B61. Solvent extractable lindane disappearance rates in flooded soils in laboratory studies.

k_1 (day^{-1})	Concentration (μg/g)	pH	OM (%)	Temp (°C)	Soil-water Content (%)	Reference
$6.4x10^{-3}$	3.27	5.8	5.2	23	>100	Mathur and Saha, 1977
$2.9x10^{-3}$	3.27	5.8	5.2	23	>100	Ibid

Table B62. Solvent extractable PCP disappearance rates in flooded soils.

k_1 (day-1)	Concentration (μg/g)	pH	OM (%)	Clay (%)	Soil-water Content (%)	Reference
8.0×10^{-2}	100	5.8	7.9	5.4	250	Kauwatsuka and Igarashi, 1975
6.6×10^{-2}	100	6.0	7.5	4.5	250	Ibid
6.0×10^{-2}	100	4.6	1.8	20.5	250	Ibid
3.9×10^{-2}	100	5.2	1.5	21.0	250	Ibid
4.2×10^{-2}	100	5.9	3.6	22.7	250	Ibid
2.3×10^{-2}	100	5.8	1.9	23.1	250	Ibid
1.1×10^{-2}	100	6.1	1.2	22.4	250	Ibid
5.9×10^{-2}	80	--	--	--	66	Watanabe, 1978
7.9×10^{-2}	80	--	--	--	66	Ibid
1.0×10^{-1}	80	--	--	--	66	Ibid
1.1×10^{-1}	80	--	--	--	66	Ibid
8.9×10^{-2}	40	--	--	--	82	Ibid
1.2×10^{-1}	40	--	--	--	82	Ibid
7.9×10^{-2}	40	--	--	--	82	Ibid
9.3×10^{-2}	40	--	--	--	82	Ibid

Table B63. Solvent extractable PCP disappearance rates in soils incubated in the laboratory under aerobic conditions.

k_1 (day^{-1})	Concentration (µg/g)	pH	OM (%)	Clay (%)	Soil-water Content (%)	Reference
1.6×10^{-2}	100	5.8	7.9	5.4	60% WHC	Kauwatsuka and Igarashi, 1975
2.7×10^{-2}	100	6.0	7.5	4.5	60% WHC	Ibid
7.3×10^{-3}	100	4.6	1.8	20.5	60% WHC	Ibid
2.0×10^{-2}	100	5.2	1.5	21.0	60% WHC	Ibid
3.9×10^{-2}	100	4.9	1.8	22.8	60% WHC	Ibid
1.1×10^{-2}	100	6.4	1.2	27.5	60% WHC	Ibid

APPENDIX C

Table C1. Correlation coefficients between sorption maxima and selected soil properties by Ballaux and Peaslee (1975).

	Sorption maxima†	
Soil property	S_{max}^{1}	S_{max}^{2}
Clay content	0.73	0.76
Free-fe oxide	0.83*	0.22
Surface area (ethylene glycol)	0.69	0.70
Organic matter	0.27	0.87*
Ca-P	0.99**	0.52

†S_{max}^{1} and S_{max}^{2} were estimated from isotherms in which initial P concentrations were 0.06 to 0.3 and 3.1 to 4.7 μmol/ml, respectively.

Table C2. Correlation coefficients between phosphate sorption parameters and soil properties from Vijayachandran and Harter (1975).

Property	% P sorption
Fe - dithionate	0.19
- HCl-NaOH	0.21
Al - dithionate	0.46*
- HCl-NaOH	0.45*
Organic carbon	0.75**

* denotes significance at the 5% level
** denotes significance at the 1% level

Table C3. Phosphate sorption correlated with extractable Al and Fe by Williams et al. (1958).

Soil group	Tamm oxalate method			Dithionite method			Acetate soluble
	Fe_2O_3	Al_2O_3	R_2O_3	Fe_2O_3	Al_2O_3	R_2O_3	Al_2O_3
			Sorption at pH 4†				
Basic igneous	0.671*	0.964***	0.918***	-0.378	0.808**	-0.219	0.817**
Slate	0.640*	0.913***	0.909***	0.289	0.713*	0.508	0.843**
O.R.S.	0.744*	0.994***	0.988***	0.497	0.978***	0.846**	0.958***
Granitic	0.655*	0.774**	0.874***	0.480	0.886***	0.679*	0.462
Over-all	0.646***	--	0.928***	-0.020	0.862***	--	0.881***
			Sorption at pH 2.6††				
Basic igneous	0.724*	0.945***	0.921***	-0.345	0.821**	-0.185	0.912***
Slate	0.664*	0.909***	0.919***	0.440	0.825**	0.670*	0.885***
O.R.S.	0.665*	0.979***	0.958***	0.335	0.959***	0.734*	0.969***
Granitic	0.491	0.666*	0.715*	0.305	0.752*	0.492	0.236
Over-all	0.609***	--	0.870***	0.025	0.881***	0.304	--

* denotes significance at the 5% level

** denotes significance at the 1% level

*** denotes significance at the 0.1% level

† By the method Piper (1942) in which the soil was saturated with phosphate by prolonged treatment with pH 4 $(NH_4)_3PO_4$. After removing the excess with alcohol, the adsorbed phosphate was removed with 0.125 N NaOH.

†† Sorption of phosphate from pH 2.6 acetic acid solution containing KH_2PO_4 (67 mg P/100 g soil).

Table C4. Regression equations resulting from correlations of phosphate sorption and Tamm extractable Fe or Al (Williams et al., 1968).

Property	Soil Group	Regression equation	
		pH 4	pH 2.6
Tamm Al	Basic groups	$S = 0.67x + 5.28$	$S = 0.021x + 0.360$
	Slate	$S = 0.91x + 3.03$	$S = 0.039x + 0.247$
	O.R.S. + granitic	$S = 0.91x + 1.19$	$S = 0.039x + 0.151$
Tamm Fe	All	$S = 1.23x + 2.51$	$S = 0.047x + 0.230$
Tamm Fe + Al	Basic igneous	$S = 0.47x + 3.78$	$S = 0.015x + 0.305$
	O.R.S. + slate + granitic	$S = 0.70x - 0.66$	$S = 0.030x + 0.081$

S = mmoles P_2O_5/100 g soil
x = mmoles Tamm M_2O_3/100 g soil

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

Table C5. Correlation coefficients of phosphate sorption parameters versus physical and chemical properties of the soils, their clay fractions, and bottom sediments used by McCallister and Logan (1978).

Property	Adsorption maximum	Adsorption energy
Soils (n=7)		
Bray P1 "Available" P	n.s.	-0.868*
Total P	0.729	n.s.
Inorganic P	0.809*	n.s.
Fine clay	0.735	n.s.
Soil clay fractions (n=7)		
CDB-Fe	n.s.	0.841*
CDB-Al	n.s.	0.823*
Total P	n.s.	n.s.
Inorganic P	n.s.	n.s.
Organic P	0.741	n.s.
Fine clay	n.s.	0.679
Sediments (n=5)		
Amorphous Si	0.997**	n.s.
CDB-Fe	0.972**	n.s.
CDB-Al	0.847	n.s.
Oxalate-Fe	0.981**	n.s.
Oxalate-Al	0.974**	n.s.
Bray P1 "Available" P	n.s.	n.s.
Total P	0.993**	n.s.
Inorganic P	0.960**	n.s.
$CaCO_3$ equivalent	-0.850	n.s.
Total clay	0.967**	n.s.
Fine clay	0.916*	n.s.
pH	-0.923*	n.s.

Values not marked are significant at the 10% level; those marked with a "" are significant at the 5% level; those marked with a "**" are signif- at the 1% level; "n.s." indicates no significant relationship between the factors at the 10% level.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT

PAGE NUMBER
EPA-287 (Cin)
(4-76)

Table C6. Correlation and regression coeficients for phosphate sorption and properties for the tropical and British soils (Lopez-Hernand and Buruham, 1974).

	P sorption index (Bache and Williams)		P sorption capacity (Piper)	
Variable	Simple	Regress coeff.	Simple	Regress coeff.
Tropical soils				
pH	-0.210^{ns}	2.678	-0.217^{ns}	0.638
Carbon	0.044^{ns}	-0.071	0.391***	1.681
Free Fe	0.328**	0.090	0.259*	0.027
Ext. Al	0.721****	34.751	0.729****	10.574
Clay	0.447***	0.193	0.338**	0.054
British soils				
pH	-0.01^{ns}	5.796		
Carbon	-0.016^{ns}	2.429		
Free Fe	0.701****	0.447		
Ext. Al	0.633****	8.212		
Clay	0.169^{ns}	-0.156		

*, **, ***, ****, significant at 10, 5, 1, 0.1% respectively.

Table C7. Correlation coefficients and regression equations between phosphate retention and soil properties for A and B horizons (Saunders, 1965).

Soil property	Soils	(No.)	Horizon	Correlation Coeff. (r)	Regression equation†
Organic carbon	All soils	(49)	A	0.186 n.s.	
	Less gley and podzols	(43)	A	0.787***	% P retn. = 8.0 + 5.68 ± 0.70 (%C)*** % C = 1.8 + 0.11 ± 0.013 (% P retn.)***
Total nitrogen	All soils	(49)	A	0.533***	% P retn. = 16.0 + 60.1 ± 18.4 (% N)**
	Less gley and podzols	(43)	A	0.759***	% P retn. = 5.4 + 93.2 ± 12.0 (% N)***
Org. P	All soils	(49)	A	0.601***	% P retn. = 20.9 + 470 ± 90 (% org. P)***
	Less gley and podzols	(43)	A	0.552***	% P retn. = 25.3 + 400 ± 94 (% org. P)
Clay content	All soils	(49)	A	0.327*	% P retn. = 31.0 + 0.48 ± 0.20 (% clay)*
% loss on ignition	All soils	(48)	A	0.517***	% P retn. = 26.1 + 1.06 ± 0.26 (% L. on I.)***
	Less gley and podzols	(43)	A	0.914***	% P retn. = -4.0 + 3.03 ± 0.21 (% L. on I.)***

*, **, ***, significance at the levels of 0.1, 1, and 5% respectively.
† Pretention measured by the method of Piper (1942).

Table C8. Regression equations of phosphate retention on aluminum and iron values for soil groups (Saunders, 1965).

Soil group	Horizon	Tamm Al† (% P retn.)	Tamm Fe† (% P retn.)	Citrate-dithionite Fe (% P retn.)
"Crystalline" soils				
Yellow-grey earths and inter-grade to yellow-brown earths	A&AB	= 10.6 + 1.82 Al**	= 14.7 + 1.16 Fe***	= 19.1 + 0.29 Fe** --
Northern yellow-brown earths	A&AB	= 13.6 + 2.92 Al**	= 21.9 + 1.33 Fe*	= 21.0 + 0.86 Fe**
Podzols	A&AB	= -9.6 + 4.39 Al**	--	--
Brown granular loams and clays	A&AB	= 6.4 + 2.70 Al**	= 11.7 + 2.08 Fe**	= -6.8 + 0.78 Fe** --
Recent soils from alluvium	A&AB	= -14.8 + 4.04 Al**	= -14.8 + 4.04 Fe**	--
"Crystalline" soils (at 500 mg P/100 g soil)	A&AB	= 0.8 + 3.03 Al***	= 13.7 + 1.70 Fe***	-- --
"Amorphous" soils				
High country and southern and central yellow-brown earths	A&AB	= 16.4 + 1.62 Al***	= 14.3 + 2.65 Fe***	= 2.06 + 1.49 Fe**

*, **, ***, significance at the levels of 0.1, 1, 5%, respectively.

† Pretention measured by the method of Piper (1942).

Table C9. Correlation coefficients for soil groups between phosphate retention† and aluminum and iron values (Saunders, 1965).

Soil group	Horizon	Tamm Al	Tamm Fe	Tamm Al + Fe	Neutral citrate dithionite Fe
Brown-grey earths	A + AB	0.192	-0.718	0.507	0.336
Yellow-grey earths inter-grade to yellow-brown earths	A + AB	0.734**	0.795**	0.822**	0.756**
High country, southern and central yellow-brown earths	A + AB	0.962***	0.947***	0.965***	0.886**
Northern yellow-brown earths	A + AB	0.954**	0.881*	0.934*	0.989**
Prodzols	A + AB	0.862***	0.048	0.780**	
Yellow-brown loams younger red and brown loams (at 2,500 mg P/100 g soil)	A + AB	0.315	0.113	0.333	
Brown granualar loams and clays	A + AB	0.972***	0.940**	0.987***	0.948**
Recent soils from alluvium	A + AB	0.942**	0.942**	0.944**	
"Crystalline" soils (at 500 mg p/100 g soil)	A + AB	0.873***	0.628***	0.788***	

† P retention measured by the method of Piper (1942).

*, **, ***, signifance at the levels of 0.1, 1. 5%, respectively.

Table C10. Langmuir constants published in literature.

Soil or Isotherm no.	S_{max}, µg P/g soil	k, ml/µg P	Remarks	Reference
Alligator -1	17.2	1.48	Initial P concentration: 2-10µg/ml (A)	Ballaux and Peasle (1975)
-2	28.8	0.32	10-15µg/ml (B)	
-3	45.7	0.16	20-25µg/ml (C)	
-4	46.9	0.13	40-55µg/ml (D)	
Crider -1	15.2	1.00	(A)	
-2	18.2	0.47	(B)	
-3	24.1	0.20	(C)	
-4	42.3	0.03	(D)	
Grenada -1	13.1	0.92	(A)	
-2	18.4	0.31	(B)	
-3	21.7	0.19	(C)	
-4	22.5	0.10	(D)	
Pembroke -1	14.4	0.97	(A)	
-2	17.8	0.46	(B)	
-3	25.3	0.16	(C)	
-4	27.7	0.08	(D)	
Zanesville-1	12.6	1.23	(A)	
-2	25.4	0.15	(B)	
-3	31.3	0.13	(C)	
-4	37.0	0.07	(D)	

(Continued)

Table C10 (Continued)

Soil or Isotherm no.	S_{max}, µg P/g soil	k, ml/µg P	Remarks	Reference
Soil 1	121.2	0.52	Na^+ saturated clay fraction; 0-24,000 µg P/ml in equilibrium solution	El-Nennah (1975)
Soil 2	112.7	0.37	"	
Soil 3	0.0	0.0	"	
Soil 1	113.3	0.83	Mg^{2+} saturated clay fraction; 0-24,000 µg P/ml in equilibrium solution	
Soil 2	290.3	0.68	"	
Soil 3	181.8	0.28	"	
Soil 1	166.6	1.50	Ca^{2+} saturated clay fraction; 0-24000 µg P/ml in equilibrium solution	
Soil 2	347.8	1.59	"	
Soil 3	219.1	0.33	"	
Brooks	21	0.16	P concentrations at equilibrium were 0-10 µg P/ml. Correlation coefficients (r) for the list of each isotherm in this group to the language equation from 0.864 to 0.999. Soil properties not given in this article.	Haysom (1974)
Camilleri	56	0.02		
Wesche	55	0.06		
Nicholson	166	0.03		
Ribaldone	98	0.02		
Harris	155	0.02		

(Continued)

TYPING GUIDE SHEET

Table C10. (Continued)

Soil or Isotherm no.	S_{max}, µg P/g soil	k, ml/µg P	Remarks	Reference
Makennan	187	0.05		
Quod	116	0.04		
Webster	188	0.04		
Walker	101	0.01		
Davies	140	0.04		
Daguara	225	0.04		
Elliot	193	0.06	P concentrations at equilibrium 0-10 µg P/ml. Langmuir isotherm correlation coefficients (r) for each isotherm in this group ranged from 0.864 to 0.999. Soil properties not given in this article.	Haysom (1974)
Brown	176	0.07		
Mullar	188	0.06		
McEwen	219	0.04		
Galletly	402	0.09		
Large	67	0.04		
Hackett	369	0.08		
Siddle	314	0.04		
Tobin	355	0.05		
Adams	218	0.05		
Denman	391	0.07		
Lamb	309	0.07		
Noonan	551	0.13		
Soper	164	0.04		
Williams	106	0.05		
Becus	376	0.05		
Barfield	404	0.07		
Young	322	0.13		
Lulsgate	494	2.10	Uniform surface Langmuir equation	Holford et al. (1974)
Evesham	591	4.84	Uniform surface Langmuir equation	
Aberford	314	1.45	Uniform surface Langmuir equation	
Woburn	188	1.88	Uniform surface Langmuir equation	

(Continued)

EPA-287 (Cin.)
(4-76)

Table C10 (Continued)

Soil or Isotherm no.	S_{max}, µg P/g soil	k, ml/µg P	Remarks	Reference
Lulsgate	148, 542	30.8, 0.3	Two-surface Langmuir equation. Values listed are for "high-energy" and "low-energy" surfaces, respectively.	
Evesham	219, 654	36.9, 0.5		
Aberford	182, 201	14.0, 0.1		
Weburn	114, 81	- , 0.3		
Venango	847	Not given	Initial P concentration was 0-3.75 µg P/ml; shaking time was 1 hour.	Vijayachandran and Harter (1975)
Humatas	684	"		
Catalina	683	"		
Corozal	468	"		
Eutaw	390	"		
Agawam	341	"		
Davidson	323	"		
Georgeville	262	"	Initial P concentration was 0-3.75 µg P/ml; shaking time was 1 hour.	Vijayachandran and Harter (1975)
Coto	252	"		
Coolville	228	"		
Waupun	211	"		
Vallers	175	"		
Putnam	128	"		
Edina	102	"		
Portsmouth	126	"		
Webster	83	"		
Clermont	58	"		
Nacogdoches	55	"		

(Continued)

Table C10. (Continued)

Soil or Isotherm no.	S_{max}, μg P/g soil	k, ml/μg P	Remarks	Reference
Sao Gabriel-1	73(23)	4.8(50.0)	Two-part Langmuir equations used for estimation of S_{max} and k. Numbers not in ( ) were obtained from the Langmuir equation for each of two sites; whereas, the numbers in ( ) were obtained from a "rearranged" two-site Langmuir expression. Initial concentrations of P were 0-44 μg P/ml; equilibrium concentrations of P were 0-14 μg P/ml. Region I is indicated by -1 and Region II by -2.	Syers et al. (1973)
-2	111(162)	0.1(0.2)		
Cambai -1	224(100)	4.7(15.5)		
-2	300(405)	0.1(0.3)		
Durox -1	990(420)	10.9(44.5)		
-2	902(1,300)	0.1(0.9)		
Hathaway	183, 509	4.6, 0.1	Two-surface Langmuir equation (values listed are for "high-energy" and "low-energy" surfaces, respectively.	Holford et al. (1974)
Quast	61, 185	4.5, 0.1		
Watts	127, 156	10.6, 0.2		
Anderson	76, 132	12.0, 0.2		
Soil 1	42.6	0.37	Uniform surface Langmuir equation was used. Equilibrium concentration of P was 0-12 μg/ml.	Myszka and Janowska (1973)
Soil 2	55.1	0.34		
Soil 3	50.4	0.34		
Soil 4	78.3	0.30		
Soil 5	192.3	0.96		
Soil 6	87.4	0.25		
Soil 7	663.5	0.09		
Soil 8	91.3	0.16		
Soil 9	304.1	0.16		

(Continued)

Table C10. (Continued)

Soil or Isotherm no.	S_{max}, μg P/g soil	k, ml/μg P	Remarks	Reference
gel A	4,576 (8,832)	1.23 (0.02)	Two-site Langmair expression was used. Numbers not in ( ) indicate values for term 1, and, numbers in ( ) are values for term 2.	Rajan and Perrott (1975)
gel B	21,760 (70,080)	0.21 (0.00)		
gel C	21,440 (48,000)	2.31 (0.03)		
gel D	36,000 (42,400)	3.71 (0.02)		
Waihi subsoil	7,840 (20,640)	0.89 (0.01)	SeO_3^{2-} pretreated; equilibrium P concentration was 0-1600 μ P/ml; 2-site Langmiur model used. Notation as above.	Rajan (1975)
	12,380 (16,960)	0.93 (0.01)	SeO_3^{2-} not-pretreated.	
Fe-gel -1	20,480	4.2	pH 6.0 in 0.1M NaCI	McLaughlin et al. (1977)
-2	30,080	0.05	pH 5.0 in 0.1M NaCI	
LM 52	112	7.11	Jurassic limestones; maximum equilibrium P conc. was 3 μg P/ml. Single-surface Langmuir equation; 182 hour equilibration	Holford and Mattingly (1975)
LM 67	124	6.44		
LM 70	105	9.95		
Soils				
Roselms I	287	1.69	Single-surface Langmuir equation used. Equilibrium P conc. was 0-15,000 μg P/ml;	McCallister and Logan (1978)
Broughton	209	4.89		
Roselms II	249	2.85		

(Continued)

Table C10 (Continued)

Soil or Isotherm no.	S_{max}, µg P/g soil	k, ml/µg P	Remarks	Reference
Paulding	216	4.35	24 hour equilibration time; 0.01 M CaCl$_2$ supporting electrolyte.	McCallister and Logan (1978)
Lenawee	244	0.80		
Blount	199	2.15		
Hoytville	258	1.49		
Soil clay fractions				
Roselms I	393	0.86		
Broughton	323	4.15		
Roselms II	411	1.91		
Paulding	455	1.09		
Lenawee	422	0.82		
Blount	538	7.43		
Hoytville	623	1.63		
Bottom sediments				
Independence 1 Dec. 1975	222	1.00		
Auglaize 1 Dec. 1975	4,870	0.68		
Tiffin 1 Dec. 1975	1,930	1.55		
Independence 24 Mar. 1976	3,580	1.05		
Auglaize 24 Mar. 1976	4,550	1.36		
#6	343	0.06	Single-surface Langmuir equation used. Equil. conc. range of P was 0-60 µg P/ml. Six hour equilibration time; 1:10 soil/soln. ratio; no supporting electrolyte.	Weir and Soper (1962)
#10	380	0.04		
Dicks	237	0.07		
McDonald	323	0.09		

Table C11. Description of soils used by Ballaux and Peaslee (1975).

	Soil Type				
Soil property	Alligator	Crider	Grenada	Pembroke	Zanesville
Subgroup	Vertic Haplaquept	Typic Paludalf	Glossic Fragiudalf	Mollic Daludalf	Typic Fragiudalf
Clay, %	51.0	18.5	16.9	19.5	16.4
Textural class	sicl	sil	sil	sil	sil
Surface area (ethylene glycol (m^2/g)	160	54	59	68	51
Free iron oxides*, mg/g	12.3	12.1	8.3	10.9	8.8
Organic matter, %	3.8	1.9	1.5	2.3	3.0
pH (1:1/sal: H_2O)	6.3	6.7	6.8	7.0	7.0
Phosphorus fractionation, µg P/g soil					
Al-P	25.2	57.7	15.5	50.0	15.7
Ca-P	91.6	53.3	20.2	39.4	15.3
Fe-P	76.2	71.2	48.1	65.6	31.2
Org-P	142.5	15.0	120.0	57.5	80.8

* Although not explicitly stated in the article, free iron oxides were taken as my Fe_2O_3/g soil.

Table C12. Description of soils used by Vijayachandran and Harter (1975).

Soil series	State	Subgroup	pH	Mechanical analysis			Iron	Aluminum
				Clay %	Silt %	Sand %	Dithionite (mg/g)	Dithionite (mg/g)
Venango	Ohio	Aeric Fragiaqualfs	4.7	22	49	29	21.5	3.1
Humatas	Puerto Rico	Typic Trophohumults	4.4	76	13	11	90.0	1.2
Catalina	Puerto Rico	Tropeptic Haplorthox	4.9	72	14	14	12.5	1.5
Corozal	Puerto Rico	Aquic Tropudults	4.2	62	20	18	60.0	1.2
Eutaw	Mississippi	Entic Pelluderts	4.7	39	42	19	11.0	2.1
Agawam	New Hampshire	Entic Haplorthods	6.3	7	50	43	11.0	2.4
Davidson	Georgia	Rhodic Paleudults	6.5	28	19	53	35.0	2.6
Georgeville	N. Carolina	Typic Hapludults	5.5	43	38	19	47.5	2.6
Coto	Puerto Rico	Tropeptic Haplorthox	4.5	40	4	56	70.0	2.5
Coolville	Ohio	Aquic Hapludults	4.6	28	58	14	11.5	1.8
Waupun	Wisconsin	Typic Argiudoll	7.1	21	56	23	11.0	0.9
Vallers	Minnesota	Typic Calciaquolls	7.7	18	12	70	2.5	0.2
Putnam	Missouri	Mollic Albaqualfs	6.0	19	56	25	12.0	0.9
Edina	Iowa	Typic Argialbolls	6.1	11	27	62	9.0	0.7
Portsmouth	N. Carolina	Typic Umbraquults	5.0	13	16	71	2.2	1.8
Webster	Iowa	Typic Haplaquolls	6.8	24	39	37	9.0	0.5
Clermont	Ohio	Typic Ochraqualfs	6.5	21	54	25	9.5	0.7
Nacogdoches	Texas	Rhodic Paleudults	6.7	13	39	48	97.5	3.1

Table C13. Description of soils used by Syers et al. (1973).

Soil property	Saσ Gabriel	Cambai	Durox
Classification	Vertic Argiudoll	Argiudoll	Haplohumox
pH	5.2	5.1	3.7
Clay, %	16	25	80
Exchangeable Al, meq/100 g	0.0	0.2	4.3
Oxalate Fe, mmoles/100 g	1.2	3.2	2.6
Oxalate Al, mmoles/100 g	0.9	4.0	3.3
CDB Fe, mmoles/100 g*	2.0	10.4	41.4
CDB Al, mmoles/100 g	2.6	6.7	18.5
Amorphous material, % in <2μm	19	30	37

* CDB refers to Fe or Al found in the citrate-dithionate-bicarbonate extract of the soil.

Table C14. Description of soils used by El-Nennah (1975).

				Percentage clay minerals in clay fraction			
Soil No.	% Clay	% Carbonate	% Organic Matter	Kaolinite	Illite	Montmorillonite	Vermiculite
1	2.7	0.5	1.2	75	15	-	10
2	17.2	0.0	4.6	15	85	-	-
3	63.0	0.0	1.1	-	-	100	-

Table C15. Description of soils used by Holford et al. (1974).

Soil	Series or group	Location*	% Clay	Surface Area (ethylene glycol), m^2/g	% $CaCO_3$	% Organic C
Lulsgate	Lulsgate	1	20.0	130	6.8	4.0
Evesham	Evesham	1	65.1	284	2.7	3.3
Aberford	Aberford	1	18.7	76	6.1	3.6
Woburn 95	Cottenham	1	8.3	50	0	1.2
Watts	Red brown earth	2	27.9	126	0.07	1.3
Arderson	Red brown earth	2	27.4	89	0.09	1.6
Quast	Black earth	2	43.3	306	0.58	1.2
Hathaway	Black earth	2	70.1	389	0.17	0.9

* 1-refers to soils from southern England, 2-refers to soils from eastern Australia.

Table C16. Description of soils used by Myszka and Janowska (1973).

Soil No. & horizon	Fraction <20μm, %	pH (KCl)	$CaCo_3$, % of dry weight	Fe_2O_3, % in Tamm extract	Al_2O_3, % in Tamm extract
1, A1	14	6.5	-	0.100	0.068
2, A1	24	4.8	-	0.143	0.077
3, A2	30	5.0	-	0.138	0.068
4, A1	40	5.6	-	0.244	0.104
5, A1	40	5.5	-	0.372	0.202
6, A1	42	6.6	-	0.279	0.274
7, A1	40	7.6	2.27	0.394	0.230
8, A1	-	7.6	8.86	0.125	0.087
9, A1	-	7.5	18.67	-	-

TYPING GUIDE SHEET

Table C17. Description of gels used by Rajan and Perrott (1975).

Gels	SiO_2 %	Al_2O_3 %	$\frac{Al}{Al + Si}$ (molar ratios)	Specific surface area m^2g^{-1}	Crystallinity
A	61.0	21.5	0.29	190	Amorphous
B	38.5	41.0	0.56	278	Amorphous
C	31.2	47.8	0.64	357	Amorphous
D	11.7	66.0	0.87	264	Amorphous + trace of pseudoboehmite

SiO_2, Al_2O_3, and surface area are expressed on oven dry (105 °C) basis.

EPA-287 (Cin.)
(4-76)

Table C18. Description of gels used by Rajan (1975).

Mineralogy	SiO_2 %	Al_2O_3 %	$\frac{Al}{Al + Si}$	Fe_2O_3 %	Glycol specific surface area m^2g^{-1}
Predominantly allophane--small amount of imogolite	32.9	33.6	0.54	6.9	168

All of the data are expressed on oven dry (105 °C) basis.

Table C19. Description of limestones used by Holfred and Mattingly (1975).

Sample	$CaCO_3$, %	Mg, %	P, %	Fe, µg/g	Surface Area, m^2g^{-1}
LM 52	98.5	.23	44	930	1.0
LM 67	98.7	.38	304	3,350	1.0
LM 70	98.9	.22	147	2,130	1.5

Table C20. Description of soils used by Weir and Soper (1962).

Soil	Description	pH	% OM	$CaCO_3$	Total P, mg P/g soil	Phosphorus extracted, µg P/g soil			
						Water extract	NH_4F extract	NaOH extract	H_2SO_4 extract
No. 6	Orthic Meadow developed on lacustrine clay	6.9	5.2	0.7	762	12.1	81.2	76.0	203
No. 10	Orthic Meadow developed on lacustrine clay	7.0	7.3	0.8	1015	59.1	135.0	105.3	325
Dicks	Calcareous Gleyed Rego Black developed on very fine sandy loam deltaic sediments	7.5	5.3	11.5	740	8.5	42.1	7.2	300
McDonald	Calcareous on silty clay loam deltaic deposits	7.8	5.3	42.0	670	2.4	20.2	4.0	322

Table C21. Description of soils and sediments used by McCallister and Logan (1978).

	Sand	Silt	Fine clay	Coarse clay	Total clay	Organic-C	$CaCO_3$ equiv-alent	Ph	Amor-phous Si	CDB-Fe	CDB-Al	Oxalate-Fe	Oxalate-Al
	----%				----	----%		----	----mg/g				----
Soils													
Roselms I	7.0	46.0	12.5	34.5	47.0	1.82	0	6.4	12.1	20.0	2.55	15.5	2.83
Broughton	6.6	45.1	10.8	37.5	48.3	1.74	0	7.3	10.2	21.2	2.55	6.7	2.75
Roselms II	10.4	46.8	10.9	31.9	42.8	1.76	0	6.0	11.6	25.0	2.35	13.3	3.33
Lenawee	12.4	53.7	9.5	24.4	33.9	2.13	0	6.6	12.3	17.5	3.00	15.5	5.33
Blount	35.4	42.6	4.5	17.5	22.0	1.47	0	5.4	12.5	32.5	4.70	16.3	3.50
Paulding	5.1	49.5	9.7	35.7	45.4	2.37	0	6.7	10.9	21.2	2.15	35.0	5.50
Hoytville	18.7	42.4	11.1	27.8	38.9	2.24	0	7.1	11.0	16.3	2.15	10.7	4.17
Soil clay Fractions													
Roselms I						1.66	0	nd	11.00	17.5	1.50	16.50	1.92
Broughton						1.30	0	nd	7.05	15.0	1.33	5.42	1.50
Roselms II						1.54	0	nd	7.58	14.4	1.49	13.10	2.08
Lenawee						2.78	0	nd	5.81	7.5	0.70	7.67	2.17
Blount						2.56	0	nd	5.13	11.9	1.45	10.10	1.33
Paulding						2.01	0	nd	6.46	15.0	1.15	14.30	2.42
Hoytville						2.22	0	nd	4.98	9.7	0.85	6.67	2.00
Bottom Sediments													
Independence 1 Dec. 1975	88.9	6.0	1.1	4.0	5.1	0.95	12.8	7.3	0.98	4.4	0.40	9.2	0.83
Auglaize 1 Dec. 1975	1.7	57.9	6.5	33.9	40.4	2.07	6.6	6.9	6.63	13.8	0.95	26.0	3.00
Tiffin 1 Dec. 1975	45.5	31.3	5.0	18.2	23.2	2.04	8.1	7.0	3.17	10.0	0.70	17.7	1.83
Independence 24 Mar. 1976	24.4	37.6	6.8	31.2	38.0	1.91	9.9	7.0	4.72	11.2	1.25	20.7	2.67
Augulaize 24 Mar. 1976	3.4	47.5	8.8	40.3	49.1	1.82	6.4	6.9	6.22	13.8	1.40	27.1	3.50

Table C22. Regression parameters from phosphate adsorption isotherms using $S = S_{max} - \frac{1}{k} (\frac{S}{C})$ as the regression model (S_{max} and $-\frac{1}{k}$ are regression coefficients).

Isotherm No. or Soil	S_{max}, $\frac{\mu g\ P}{g\ soil}$	$-\frac{1}{k}$, $\frac{\mu g\ P}{ml}$	k, $\frac{ml}{\mu g\ P}$	r^2	Standard errors $s_{S \cdot \frac{S}{C}}$	Standard errors $s_{S_{max}}$	Standard errors $s_{-\frac{1}{k}}$	Reference
5	922	-0.078	12.8	0.88	165	144	0.021	Munns and Fox (1976)
6	525	-0.065	15.4	0.99	38.7	37	0.008	"
7	478	-0.05	20.0	0.79	110.3	71	0.016	"
8	1,291	-0.12	8.3	0.72	318	301	0.055	"
9	553	-0.16	6.2	0.79	104	81	0.047	"
10	398	-0.055	18.2	0.78	44	34	0.017	Holford and Mattingly (1976)
11	383	-0.15	6.7	0.80	67	36	0.031	"
12	278	-0.22	4.5	0.84	36	32	0.053	"
13	324	-0.082	12.2	1.90	31	28	0.016	"
14	302	-0.153	6.5	0.85	35	31	0.038	"
15	284	-0.29	3.4	0.86	30	27	0.068	"
16	2,009	-0.35	2.9	0.60	483.0	269	0.109	Hope and Syers (1976)
17	1,936	-0.36	2.8	0.78	384	390	0.110	"
18	1,517	-0.25	4.0	0.46	533	278	0.105	"
19	343	-1.16	0.86	0.40	105	76	0.815	Singh and Tabatabai (1976)
20	388	-1.55	0.65	0.89	44.6	35	0.322	"
21	343	-1.76	0.57	0.89	38.8	30	0.365	"
22	328	-2.26	0.44	0.83	45.0	34	0.585	"
23	346	-3.92	0.26	0.88	37.0	33	0.838	"
24	340	-3.81	0.26	0.88	36.8	31	0.807	"
25	333	-2.59	0.39	0.95	21.7	17	0.33	"
26	313	-2.47	0.40	0.89	31.5	24	0.48	"
27	265	-2.08	0.48	0.79	39.6	27	0.62	"

(Continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

Table C22. (Continued)

Isotherm No. or Soil	S_{max}, $\frac{\mu g\ P}{g\ soil}$	$-\frac{1}{k}$, $\frac{\mu g\ P}{ml}$	k, $\frac{ml}{\mu g\ P}$	r^2	Standard errors			Reference
					$s_{S \cdot \frac{S}{C}}$	$s_{S_{max}}$	$s_{-\frac{1}{k}}$	
28	253	-2.44	0.41	0.88	26.2	18	0.52	Singh and Tabatabai (1976)
29	251	-3.94	0.25	0.90	22.5	18	0.77	"
30	205	-7.84	0.13	0.80	24.0	24	2.24	"
31	710	-2.40	0.42	0.98	20.1	21.4	0.19	Edzwald, Toensing, and
32	82	-2.20	0.45	0.33	19.8	16.2	1.56	Leung (1976)
33	2,331	-4.69	0.21	0.89	106.5	111.6	0.67	"
34	72.4	-0.035	28.6	0.002	18.2	7.8	0.27	"
35	54	-6.17	0.16	0.88	12.4	14.5	1.63	"
36	152	-2.96	0.34	0.87	9.5	9.65	0.66	"
37	603	-0.49	2.04	0.64	95	74	0.213	"
38	629	-0.314	3.18	0.87	58	33	0.069	"
40	708	-2.11	0.47	0.98	22	22	0.185	"
43	2,332	-3.06	0.33	1.00	21	25	0.11	"
44	2,298	-4.69	0.21	0.83	137.9	143.7	0.87	"
45	2,369	-2.54	0.39	0.93	100.0	99.4	0.39	"
49	638	-0.505	1.98	0.15	174	730	0.829	Barrow (1972)
50a	1,040	-0.074	13.5	0.84	137	132	0.019	"
50b	224	-0.116	8.62	0.92	22	24	0.025	"
50c	451	-0.042	23.8	0.89	44	51	0.010	"
50d	633	-0.099	10.1	0.72	103	154	0.044	"
50e	1,385	-0.110	9.09	0.91	143	197	0.024	"
51	2,196	-0.031	32.3	0.58	527	250	0.013	Ryden, McLaughlin, and
52	32,900	-0.011	90.9	0.55	4,840	2,230	0.005	Syers (1977a)
52a	3,330	-0.016	62.5	0.69	270	143	0.006	"

(Continued)

Table C22. (Continued)

Isotherm No. or Soil	S_{max}, $\frac{\mu g\ P}{g\ soil}$	$-\frac{1}{k}$, $\frac{\mu g\ P}{ml}$	k, $\frac{ml}{\mu g\ P}$	r^2	Standard errors			Reference
					$s_{S \cdot \frac{S}{C}}$	$s_{S_{max}}$	$s_{-\frac{1}{k}}$	
57	4,420	-0.496	2.02	0.87	494	380	0.112	Ryden and Syers (1975)
58	3,030	-0.491	2.04	0.79	368	268	0.147	"
59	2,890	-0.420	2.38	0.91	196	143	0.078	"
60	2,490	-0.281	3.56	0.82	263	172	0.077	"
61	1,840	-0.289	3.46	0.82	146	98	0.077	"
62	1,800	-0.403	2.48	0.85	131	90	0.097	"
63	2,150	-0.398	2.51	0.87	224	146	0.091	"
64	1,480	-0.267	3.75	0.58	282	156	0.133	"
65	1,660	-0.357	2.80	0.89	146	94	0.071	"
66	1,240	-0.184	5.43	0.85	140	81	0.044	"
67	945	-0.225	4.44	0.79	143	86	0.068	"
68	461	-0.367	2.72	0.81	67	43	0.103	"
69	397	-0.306	3.27	0.78	58	35	0.095	"
70	347	-0.498	2.01	0.81	38	30	0.140	"
71	318	-0.557	1.80	0.78	42	30	0.171	"
72	299	-0.886	1.13	0.82	37	28	0.240	"
73	275	-0.158	6.33	0.62	76	43	0.072	"
74	292	-0.109	0.90	0.90	28	23	0.219	"
75	245	-0.822	1.22	0.83	32	23	0.214	"
76	220	-0.935	1.07	0.84	29	22	0.234	"
77	206	-0.719	1.39	0.80	36	24	0.206	"
78	2,080	-0.016	62.5	0.69	517	296	0.006	"
79	1,300	-0.083	12.0	0.85	172	139	0.020	"
80	278	-0.088	11.4	0.91	26	21	0.016	"
81	171	-0.109	9.17	0.85	17	16	0.026	"

Table C23. Descriptions of soils and experimental parameters used by Minns and Fox (1976) for from whose isotherms Langmuir parameters given in Table 3 were computed.

Isotherm No.	Soil or adsorbent used	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
5	Halii soil	10:1	1 mM $CaCl_2$	No	6 days	0-3	Shaken twice daily
6	Molokai soil	10:1	1 mM $CaCl_2$	No	6 days	0-3	in centrifuge tubes.
7	Wakiawa soil	10:1	1 mM $CaCl_2$	No	6 days	0-3	Toluene added.
8	Kula	10:1	1 mM $CaCl_2$	No	6 days	0-3	
9	Wahiawa soil	10:1	1 mM $CaCl_2$	No	6 days	0-3	

Soil properties:

Soil type*	pH†	H_2O†	Organic carbon	Mineralogy
		-------%	------	
Molokai silty loam Typic Torrox, isohypothermic	5.7	30	1.0	Kaolinite sesquioxides
Wahiawa silty clay Tropeptic Eutrustox, isothermic	4.7	35	1.7	Kaolinite, hematite, mica
Halii gravelly silty clay Typic Gibbsihumox, isothermic	5.1	33	3.9	Gibbsite, goethite, Kaolinite, amorphous
Kula loam Typic Eutrandept, media, isothermic	5.8	64	9.7	Amorphous Fe and Al oxides

* Samples taken from Hawaiian Islands. All samples from 0-15 cm depth except Molakai soil, 20-40 cm.

† pH measured in 1 mM $CaCl_2$; % H_2O at approximately 0.1 bar suction.

TYPING GUIDE SHEET

Table C24. Description of soils and experimental parameters used by Holford and Mattingly (1976) and Russell (1963) from whose isotherms Langmuir parameters were computed.

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
10	Castle Cary	--	--	--	--	--	No experimental methods given in article
11	Longborough						
12	Andoversford-low P						
13	Dunkirk						
14	Sherborne						
15	Andoversford-high P						

Soil Properties:

Soil	P applied in field kg/ha	% clay	pH	% Organic matter	% $CaCO_3$	% Total P	µmoles/ℓ $CaCl_2$	p.p.m. P 0.5N-Acetic Acid	p.p.m. P Acetic acid-sodium acetate	p.p.m. P 0.5M-$NaHCO_3$	p.p.m. P 1% Citric acid
Sherborne	307	35.3	8.0	6.2	15.5	0.123	1.25	43.1	3.8	23.6	158
Andoversford	142	29.0	7.9	5.5	8.6	0.098	1.19	24.8	3.8	16.2	130
	274		8.0	5.6	11.8	0.107	2.08	48.0	6.0	29.0	235
Longborough	175	40.5	8.0	6.3	12.6	0.119	0.86	32.4	3.4	23.8	230
Dundirk	153	35.7	7.8	5.3	7.6	0.117	0.31	16.0	3.0	11.3	120
Castle Cary	44	38.5	7.5	5.7	2.2	0.370	1.04	457.0	6.0	31.0	780

EPA-287 (Cin.) (4-76)

Table C25. Experimental parameters used by Hope and Syers (1976) from whose isotherms Langmuir parameters were computed.

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Reaction Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
16	Ramiha soil	5:1	0.1 M NaCl	--	40 hrs.	0-6	Hg. Cl_2 added. End-over-end tumbling of polycarbonate centrifuge tubes.
17	Ramiha soil	10:1	0.1 M NaCl		40 hrs.	0-6	
18	Ramiha soil	40:1	0.1 M NaCl		40 hrs.	0-6	

Soil properties: Not given

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Table C26. Experimental parameters used by Singh and Tabatabai (1976) from whose isotherms Langmuir parameters were computed.

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
19	Webster soil	10.1	0.01 M $CaSO_4$	No	24 hrs.	0-30	Plastic centrifuge tubes shaken on a reciprocating shaker.
20	Webster soil	10:1	0.01 M $Ca(NO_3)_2$	No	24 hrs.	0-30	
21	Webster soil	10:1	0.01 M NaCl	No	24 hrs.	0-30	
22	Webster soil	10:1	0.01 M $CaCl_2$	No	24 hrs.	0-30	
23	Webster soil	10:1	H_2O	No	24 hrs.	0-30	
24	Webster soil	10:1	0.01 M $NaHCO_3$	No	24 hrs.	0-30	
25	Ida soil	10:1	0.01 M $CaSO_4$	No	24 hrs.	0-30	
26	Ida soil	10:1	0.01 M $Ca(NO_3)_2$	No	24 hrs.	0-30	
27	Ida soil	10:1	0.01 M NaCl	No	24 hrs.	0-30	
28	Ida soil	10:1	0.01 M $CaCl_2$	No	24 hrs.	0-30	
29	Ida soil	10:1	H_2O	No	24 hrs.	0-30	
30	Ida soil	10:1	0.01 M $NaHCO_3$	No	24 hrs.	0-30	

Soil properties:

Soil	pH†	Phosphorus					Free Fe*
		Total ($HClO_4$ dig.)	Organic	Water-soluble	Olsen-P ($NaHCO_3$)	Bray-P (NH_4F)	
		ppm					%
Webster	6.1	589	102	10.4	32	39	0.15
Ida	8.0	774	42	0.5	3	2	0.75

†pH determined in H_2O; soil: H_2O = 1:2.5
*Citrate-dithioncte-bicarbonate extract

Table C27. Experimental parameters used by Edzwald et al. (1976) from whose isotherms Lanqmuir parameters were computed.

Isotherm No.	Adsorbent	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
31	Montmorillonite	Not given	0.002 M	Yes	24 hrs.	0-20	Buffered systems with $NaHCO_3$. Erlenmeyer flasks used. Temperature was 28°C.
32	Kaolinite	Not given	$NaHCO_3$	Yes	24 hrs.	0-20	
33	Illite	Not given	$NaHCO_3$	Yes	24 hrs.	0-20	
34	Kaolinite	Not given	$NaHCO_3$	Yes	24 hrs.	0-20	
35	Kaolinite	Not given	$NaHCO_3$ + 0.03 M Na_2SO_4	Yes	24 hrs.	0-20	
36	Kallinite	Not given	$NaHCO_3$ + 0.5 M NaCl	Yes	24 hrs.	0-20	
37	Montmorillonite	Not given	$NaHCO_3$ + 0.03 M Na_2SO_4	Yes	24 hrs.	0-20	
38	Montmorillonite	Not given	$NaHCO_3$ + 0.5 M NaCl	Yes	24 hrs.	0-20	
40	Montmorillonite	Not given	$NaHCO_3$ + 0.5 M NaCl	Yes	24 hrs.	0-20	
43	Illite	Not given	$NaHCO_3$ + 0.03 M Na_2SO_4	Yes	24 hrs.	0-20	
44	Illite	Not given	$NaHCO_3$ + 0.03 M Na_2SO_4	Yes	24 hrs.	0-20	
45	Illite	Not given	$NaHCO_3$ + 0.5 M NaCl	Yes	24 hrs.	0-20	

Adsorbent properties:

Clay	Acid extractable ($HCl-H_2SO_4$) Fe, mg/g	Al, mg/g
Kaolinite-API #3	0.028	0.14
Montmorillonite-API #21	0.171	0.68
Illite-API #36	2.38	2.45

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET

Table C28. Experimental parameters used by Barrow (1972) from whose isotherms Langmuir parameters were computed.

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
49	Soil 1	5:1	H_2O	No	24 hrs.	0-0.6	Temperature was 25°C. A reciprocating shaker was used.
50a	Soil 1	5:1	0.02 $\underline{M}$ $CaCl_2$	No	24 hrs.	0-0.6	
51b	Soil 2	5:1	H_2O	No	24 hrs.	0-0.6	
50c	Soil 2	5:1	0.02 $\underline{M}$ $CaCl_2$	No	24 hrs.	0-0.6	
50d	Soil 3	5:1	H_2O	No	24 hrs.	0-0.6	
50e	Soil 3	5:1	0.02 $\underline{M}$ $CaCl_2$	No	24 hrs.	0-0.6	

Soil properties:

Number	Location	pH in 0.01 M CaCl	Total N (per cent)	Free Fe (per cent)	Free Al (per cent)	Exchangeable (me./100 g)				Cation Exchange Capacity (me./100 g)
						Na	K	Ca	Mg	
1	Robertson, N.W. Wales	4.2	0.38	5.2	1.2	0.17	0.18	2.12	1.44	16.1
2	Wungong, W. Australia	5.2	0.16	0.8	0.3	0.15	0.21	2.87	1.11	10.3
3	Manjimup, W. Australia	6.2	0.25	2.1	0.5	0.50	0.83	11.7	4.9	26.3

EPA-287 (Cin.)
(4-76)

Table C29. Experimental parameters used by Ryden et al. (1977a,b) from whose isotherms Langmuir parameters were computed.

Isotherm No.	Adsorbent	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
51	Okaihau	40:1	0.1 M NaCl	No	192 hrs.	0-8	Temperature was 24°C. Reciprocating shaker used to agitate polycarbonate tubes. $HgCl_2$ (147 μmole/l) added to prevent microbial growth. Synthetic goethite and Fe-gel.
52	Fe-gel	40:1	0.1 M NaCl, pH7	Yes	192 hrs.		
52a	Goethite	40:1	0.1 M NaCl, pH7	Yes	192 hrs.		

Absorbent properties:

1. Okaihau soil-see description at Isotherm No. 64.
2. Fe-gel, N_2 surface area-280 m^2g^{-1}; amorphous to x-rays.
3. Goethite-1 to 0.1 μm fraction used after aging 10 months at room temperature.

TYPING GUIDE SHEET
EPA-287 (Cin.)
(4-76)

Table C30. Experimental parameters used by Ryden and Syers (1975) from whose isotherms Langmuir parameters were computed.

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
57	Egmont	40:1	$10^{-2}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	End-over-end shaker used at 23°C. $HgCl_2$ (40 g/ml) added to each tube.
58	Egmont	40:1	$10^{-1}\underline{M}$ NaCl	No	40 hrs.	0-10	
59	Egmont	40:1	$10^{-3}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
60	Egmont	40:1	$3x10^{-2}\underline{M}$ NaCl	No	40 hrs.	0-10	
61	Egmont	40:1	$10^{-4}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
62	Egmont	40:1	$10^{-4}\underline{M}$ NaCl or H_2O	No	40 hrs.	0-10	
63	Okaihau	40:1	$10^{-2}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
64	Okaihau	40:1	$10^{-1}\underline{M}$ NaCl	No	40 hrs.	0-10	
65	Okaihau	40:1	$10^{-3}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
66	Okaihau	40:1	$10^{-4}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
67	Okaihau	40:1	H_2O	No	40 hrs.	0-10	
68	Porirau	40:1	$10^{-2}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
69	Porirau	40:1	$10^{-1}\underline{M}$ Na or $10^{-3}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
70	Porirau	40:1	$3x10^{-2}\underline{M}$ NaCl	No	40 hrs.	0-10	
71	Porirau	40:1	$10^{-4}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
72	Porirau	40:1	$10^{-4}\underline{M}$ NaCl or H_2O	No	40 hrs.	0-10	
73	Waikakahi	40:1	$10^{-2}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
74	Waikakahi	40:1	$10^{-3}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
75	Waikakahi	40:1	$10^{-4}\underline{M}$ $CaCl_2$	No	40 hrs.	0-10	
76	Waikakahi	40:1	$3x10^{-2}\underline{M}$ NaCl or H_2O	No	40 hrs.	0-10	

(Continued)

Table C30. (Cpntinued)

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks
77	Waikakahi	40:1	$10^{-1}M$ NaCl	No	40 hrs.	0-10	
78	Egmont	40:1	$10^{-2}\overline{M}$ $CaCl_2$	No	40 hrs.	0-1	
79	Okaihau	40:1	$10^{-2}\overline{M}$ $CaCl_2$	No	40 hrs.	0-1	
80	Porirau	40:1	$10^{-2}\overline{M}$ $CaCl_2$	No	40 hrs.	0-1	
81	Waikakahi	40:1	$10^{-2}\underline{M}$ $CaCl_2$	No	40 hrs.	0-1	

Soil properties:

Soil	Horizon	pH	Exchangeable Ca (mmoles/100 g)	Exchangeable Al (mmoles/100 g)	$CaCO_3$ (%)*	CDB Crystalline Fe (mmoles/100 g)	CDB Al (mmoles/100 g)	Short-range Order Fe (mmoles/100 g)	Short-range Order Al (mmoles/100 g)	Clay (%)*	Surface area (m^2/g)
Egmont	BC	7.1	1.17	1.03	0	21	78	19.5	133	41	52
Okaihau	B_2	5.0	0.00	0.57	0	139	124	5.2	18.0	31	64
Porirua fine	B_1	5.0	0.40	0.72	0	7.3	10.0	3.3	5.6	15	9.2
Waikakahi	B_3Ca	7.7	n.d.	0.00	27	17.6	8.0	4.3	4.6	n.d.	17.8

(Continued)

---

* Data from New Zealand Soil Bureau (1968).

Table C30. (Continued)

Isotherm No.	Soil	Soln:soil ratio	Supporting Electrolyte	pH Control	Shaking Time	Equil. P conc. range, $\frac{\mu g\ P}{ml}$	Remarks

Soil properties (Continued)

Effect of support media on supernatant pH values
(average values over the isotherm)

Soil	pH values in						
	10^{-3}M Ca	10^{-3}M Ca	10^{-4}M Ca	10^{-1}M Na	3×10^{-3} Na	10^{-4}M Na	Water
Egmont	6.78	6.79	7.28	6.70	6.83	7.33	7.34
Okaihau	4.74	4.84	5.77	5.05	5.62	--	6.33
Porirua	4.44	4.79	5.36	4.55	4.88	5.90	5.79
Waikakahi	7.97	7.91	8.13	8.05	8.09	--	7.99

Table C31. Data used for calculating Langmuir constants (listed in Table C22) from isotherms.

Isotherm No.	Description	P sorbed, μg P/g soil	Equil. conc. of P, μg P/ml	S/C, ml/g soil
Munns and Fox (1976)				
(5)	Hallii soil	110	0.1	11,000
		295	0.037	8,000
		500	0.163	3,100
		1,000	1.215	820
(6)	Molokai soil	50	.0067	7,500
		300	.10	3,000
		500	.702	710
(7)	Wahiawa soil	50	.0058	8,600
		180	.043	4,200
		300	.186	1,600
		400	.500	800
		600	1.49	400
(8)	Kula soil	100	.0149	6,700
		550	.0702	7,800
		1,000	.289	3,500
		1,200	2.65	450
(9)	Wahiawa soil	100	.0316	3,160
		200	.120	1,700
		300	.295	1,000
		450	.712	630
		600	1.310	460
Holford and Mattingly (1976)				
(10)	Sherborne Series Castle Cary	220	0.060	3,660
		260	0.120	2,160
		294	0.240	1,220
		325	0.360	900
		435	1.280	340

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Holford and Mattingly (1976)				
(11)	Longborough	122	0.060	2,030
		158	0.120	1,310
		204	0.280	720
		328	1.240	260
		435	2.720	160
(12)	Andoversford	80	0.080	1,000
		116	0.160	720
		154	0.400	380
		179	0.460	380
		289	2.160	130
(13)	Dunkirk soil	106	0.040	2,650
		146	0.060	2,430
		187	0.136	1,370
		216	0.220	980
		324	0.840	380
(14)	Sherborne	111	0.080	1,380
		146	0.160	910
		188	0.320	580
		214	0.520	410
		314	1.600	190
(15)	Andoversford	107	0.160	660
		142	0.322	440
		179	0.640	280
		204	0.960	210
		289	2.68	100
Hope and Syers (1976)				
(16)	Solution:Soil ratio 5:1:	133	.06	2,200
		400	.09	4,400
		972	.22	4,400
		1,178	.47	2,500
		1,389	.83	1,700

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Hope and Syers				
(16)	Solution:Soil ratio 5:1:	1,680	1.78	940
		1,851	2.83	650
		2,022	3.83	530
		2,191	5.22	420
(17)	Solution:Soil ratio 10:1:	200	.06	3,300
		356	.08	4,500
		489	.10	4,900
		956	.35	2,700
		1,956	3.89	500
(18)	Solution:Soil ratio 40:1:	43	.04	1,100
		238	.06	4,000
		541	.11	4,900
		643	.16	4,000
		930	.43	2,200
		1,297	1.57	830
		1,557	2.53	620
		1,784	4.42	400
		1,914	5.83	330
Singh and Tabatabai (1976)				
(19)	$CaSO_4$ Webster soil	100	.562	180
		191	1.410	140
		265	3.330	80
		339	6.410	53
		395	9.740	40
(20)	$Ca(NO_3)_2$	97	.481	200
		189	1.732	110
		255	4.444	58
		322	8.111	40
		391	12.010	33

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Singh and Tabatabai (1976)				
(21)	NaCl	95	.624	152
		174	2.434	71
		241	5.478	44
		303	10.816	28
		343	15.849	22
(22)	$CaCl_2$	92	.811	113
		166	3.421	49
		230	7.305	32
		283	11.700	24
		333	17.783	19
(23)	H_2O	87	1.233	71
		159	4.217	38
		226	9.165	25
		263	12.328	21
		326	20.000	16
(24)	$NaHCO_3$	87	1.233	71
		159	4.217	38
		224	9.742	23
		283	16.876	17
		315	18.738	17
(25)	Ida Soil $CaSO_4$	91	.924	98
		169	3.082	56
		230	6.989	33
		276	12.271	22
		311	17.557	18
(26)	$Ca(NO_3)_2$	90	.950	95
		163	3.080	53
		214	8.360	26
		267	12.430	21
		306	18.012	17

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
(27)	NaCl	90	1.000	90
		156	4.969	31
		202	10.000	20
		243	15.849	15
		283	22.103	13
(28)	$CaCl_2$	88	1.227	72
		150	5.000	30
		194	10.700	18
		226	16.939	13
		257	25.770	10
(29)	H_2O	85	1.896	45
		137	6.150	22
		185	13.421	14
		213	20.100	11
		238	26.438	9
(30)	$NaHCO_3$	65	3.415	19
		102	10.000	10
		133	18.012	7
		161	23.263	7
		183	31.623	6
Edzwald, Toensing, and Leung (1976)				
(31)	Montmorillonite + $NaHCO_3$	310	1.78	174
		380	2.89	131
		470	5.00	94
		560	9.32	60
		620	13.54	46
(32)	Kaolinite + $NaHCO_3$	44.0	2.22	20
		44.0	4.44	10
		44.0	7.1	6
		66.0	9.32	7
		88.0	14.43	6
		88.0	21.0	5

(continued)

EPA-287 (Cin)
(4-76)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, μg P/g soil	Equil. conc. of P, μg P/ml	S/C, ml/g soil
Edzwald, Toensing, and Leung (1976)				
(33)	Illite + $NaHCO_3$	1,130	4.22	268
		1,240	5.66	220
		1,380	7.99	173
		1,750	10.99	160
		1,690	13.32	127
		1,750	15.98	110
		1,840	17.32	106
		1,950	19.76	99
(34)	Kaolinite no salt	69	0.86	80
		69	2.86	24
		51	4.3	12
		64	6.9	9
		55	7.1	8
		109	8.6	13
		80	9.4	9
		69	13.1	5
		80	17.4	5
(35)	Kaolinite + 0.03 $\underline{M}$ Na_2SO_4	68.6	2.3	3.2
		97.1	5.1	5.4
		114	13.1	11.4
		137	18.0	12.0
(36)	Kaolinite + 0.5 $\underline{M}$ NaCl	80	3.8	21.0
		103	5.0	20.6
		120	12.5	9.6
		129	16.9	7.6
		137	21.0	6.5
(37)	Montmorillonite + 0.03 $\underline{M}$ Na_2SO_4	286	0.6	477
		400	0.7	571
		457	2.6	176
		514	4.6	112
		657	7.4	89

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Edzwald, Toensing, and Leung (1976)				
(38)	Montmorillonite + 0.5 M NaCl	314	0.3	1,047
		486	2.3	211
		571	4.2	136
		629	8.6	73
		671	13.1	51
(40)	Montmorillonite + no salt	322	1.70	189
		400	2.82	143
		486	5.14	95
		571	9.43	60
		637	13.7	46
(43)	Illite + 0.03 M Na_2SO_4	1,257	3.6	353
		1,600	6.8	234
		1,800	10.4	173
		1,896	12.5	152
		1,966	17.1	115
(44)	Illite + no salt	1,120	4.18	268
		1,210	5.70	212
		1,320	7.98	165
		1,740	10.83	161
		1,670	13.49	124
		1,730	15.96	108
		1,820	17.39	105
		1,950	19.81	98
(45)	Illite + 0.5 M NaCl	1,320	3.04	434
		1,600	6.58	243
		1,800	9.69	194
		2,060	14.54	142
		2,120	18.81	113

(continued)

TYPING GUIDE SHEET
EPA-287 (Cin)
(4-76)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, μg P/g soil	Equil. conc. of P, μg P/ml	S/C, ml/g soil
Barrow (1972)				
(49)	Soil 1--	86	0.01	860
	no Ca^{2+}	156	0.17	918
		241	0.24	1,004
		379	0.53	715
(50a)	Soil 1--	241	0.02	12,050
	0.02 M Ca^{2+}	397	0.06	6,616
		517	0.08	6.462
		724	0.19	3,810
		1,000	0.40	2,500
(50b)	Soil 2--	48	0.03	1,600
	no Ca^{2+}	96	0.11	873
		152	0.23	661
		193	0.51	378
(50c)	Soil 2--	152	0.02	7,600
	0.02 M Ca^{2+}	207	0.04	5,175
		303	0.11	2.754
		400	0.18	2,222
(50d)	Soil 3--	121	0.03	4,033
	no Ca^{2+}	241	0.05	4,820
		379	0.15	2,526
		483	0.26	1,858
(50e)	Soil 3--	121	0.01	12,100
	0.02 M Ca^{2+}	397	0.05	7,580
		741	0.12	6,175
		1,000	0.24	4,166
Ryden, McLaughlin, and Syers (1977)				
(51)	Okaihau-	2,742	7.31	375
	equilibrium	2,583	5.26	491
		2,171	1.83	1,186
		1,669	0.57	2,928
		1,314	0.18	7,300
		914	0.02	45,714

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Ryden, McLaughlin, and Syers (1977)				
(52)	Fe-gel	38,400	4.98	7,710
		36,053	3.02	11,900
		32,700	1.78	18,400
		29,200	0.75	38,900
		25,600	0.32	80,000
		21,300	0.02	1,060,000
(52a)	Synthetic goethite	3,630	7.09	512
		3,420	3.43	997
		3,140	1.14	2,754
		2,930	0.46	6,369
		2,560	0.05	51,106
Ryden and Syers (1975)				
(57)	Aa	575	0	
		1,759.5	.29	6,065
		2,162	.58	3,730
		2,921	1.45	2,041
		3,829.5	4.21	1,467
		4,600	9.57	481
(58)	Ab	1,529.5	.435	3,500
		1,725	1.02	1,690
		2,438	2.55	956
		2,783	4.50	618
		3,162.5	7.54	419
(59)	Ac	1,529.5	.435	3,500
		1,897.5	1.02	1,860
		2,415	2.8	863
		2,587.5	3.87	668
		2,932.5	7.15	410
(60)	Ad	1,322.5	0.29	4,560
		1,725.0	1.02	1,690
		2,070.0	2.12	976
		2,369.0	4.15	570
		2,679.5	7.05	380

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Ryden and Syers (1975)				
(61)	Ae	1,150.0	0.44	2,600
		1,380.0	1.45	950
		1,633.0	3.05	535
		1,782.5	4.50	396
		1,897.5	6.38	297
(62)	Af, g	1,092.5	0.58	1,880
		1,380.0	2.03	680
		1,552.5	3.63	428
		1,725.0	5.66	305
		1,840.0	7.40	249
(63)	Ba	950	.29	3,275
		1,410	1.16	1,215
		1,670	2.09	799
		2,130	6.09	350
		2,240	9.57	234
(64)	Bb	750	.29	2,586
		1,120	1.02	1,100
		1,570	4.21	373
		1,690	6.24	270
		1,840	9.48	140
(65)	Bc	775	.29	2,672
		1,120	1.02	1,100
		1,410	3.05	467
		1,550	4.93	315
		1,770	9.57	185
(66)	Be	570	.145	3,930
		830	.67	1,240
		1,121	3.19	351
		1,240	5.95	208
		1,350	8.99	150
(67)	Bg	390	.145	2,690
		600	.73	822
		770	2.09	368
		950	4.06	234
		1,060	7.4	143

(continued)

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Ryden and Syers (1975)				
(68)	Ca	185	.22	841
		263	.73	360
		359	2.18	165
		424	4.35	97
		520	9.57	54
(69)	Cb,c	179	.23	780
		251	1.02	246
		335	2.84	118
		389	5.22	75
		442	8.99	49
(70)	Cd	173	0.44	394
		203	1.02	199
		263	2.09	126
		311	3.48	89
		353	6.09	58
(71)	Ce	149	0.44	340
		191	1.29	148
		239	2.61	92
		293	5.16	57
		341	8.85	39
(72)	Cf,g	120	0.54	222
		173	1.74	99
		215	3.19	67
		263	5.74	46
		311	9.72	32
(73)	Da	91	0.07	1,300
		136	0.44	309
		223	1.89	118
		282	4.06	69
		354	8.41	42
(74)	Dc	286	9.12	31
		250	6.18	40
		191	2.79	68
		145	1.32	110
		100	0.53	189

(continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

Table C31. (Continued)

Isotherm No.	Description	P sorbed, µg P/g soil	Equil. conc. of P, µg P/ml	S/C, ml/g soil
Ryden and Syers (1975)				
(75)	De	255	9.71	26
		227	6.76	34
		173	3.23	54
		132	1.32	100
		91	0.44	207
(76)	Dd,g	223	8.09	28
		191	5.15	37
		150	2.65	57
		109	1.32	82
		64	0.35	182
(77)	D,b	227	9.41	24
		191	6.47	30
		154	3.53	44
		91	0.88	103
		56	0.24	233
(78)	Aa	2,581	0.922	2,800
		2,194	0.469	4,680
		1,581	0.172	9,190
		1,032	0.034	30,300
		613	0.006	102,000
(79)	Ba	1,372	0.906	1,510
		989	0.297	3,330
		798	0.188	4,240
		574	0.078	7.360
		383	0.031	12,400
(80)	Ca	281	0.938	299
		225	0.438	514
		188	0.219	858
		141	0.109	1,290
(81)	Da	169	0.781	216
		131	0.406	323
		113	0.281	402
		94	0.156	603
		66	0.063	1,050

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-207 (Cin.)
(4-75)

Table C32. Freundlich constants found in literature.

Soil or Isotherm no.	Freundlich K	n	Remarks	Reference
Illinois River, >0.05μm Spoon River, >0.05μm	0.185	0.321	Equilibruim P concentrations were 0-10 μgP/ml. Membrane filter used in separating solids from solution. pH was controlled by adding HCl; aerobic conditions throughout.	Wang (1974)
Kaolinite	0.562	0.388		Low and Black (1950)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD, BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)